Science Press

Journal of Arid Land

2012, 4(2): 221–229

doi: 10.3724/SP.J.1227.2012.00221

jal.xjegi.com; www.chinasciencejournal.com

Interactions between water-land resources and oasis urban development at the northern slopes of the Tianshan Mountains, Xinjiang, China

Jun LEI[1*], Wen DONG[1], Yu YANG[2,3], Jie LU[4], Thomas STERR[5]

[1] Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China;
[2] Institute of Geographic Sciences and Nature Resources Research, Chinese Academy of Sciences, Beijing 100101, China;
[3] Graduate University of Chinese Academy of Sciences, Beijing 100049, China;
[4] Xinjiang Normal University, Urumqi 830054, China;
[5] Geographical Institute of Heidelberg University, Heidelberg 69120, Germany

Abstract: Urban development in arid and semi-arid regions is largely constrained by fragile physical environments. The characteristics of an urban settlement are different from those in other regions of China. This paper analyses the coupling characteristics and spatio-temporal variations for oasis urban development and water-land resources at the northern slopes of the Tianshan Mountains by principal component analysis and a coupling degree model. The result shows that the degree and change in regional use of water and land resources are different among the studied cities/counties during their development. The built-up areas of these cities/counties have changed little with increasing populations and urbanization levels, which well reflects that the urban development in arid and semi-arid regions is limited by oasis areas. Per capita amount of water supplied, however, presented a trend of slowed growth with increasing levels of urbanization. Water consumption gradually increased with urban development and the improvement of people's living standards, accompanied by enhanced water use efficiency. The level of urbanization can be assessed through the coupling degree between oasis urban development and the use of water and land resources. A high coupling degree represents a high level of comprehensive urban development and use of water-land resources. Alternatively, a low coupling degree denotes a low level of urban development and water-land resource use.

Keywords: oasis urban development; water-land resources; coupling factors; coupling degree; northern slopes of the Tianshan Mountains

Water and land are basic and strategic resources in regional eco-environmental systems, which contain sensitive factors that set a limit to urban development (Chan and Yao, 1999; Zheng and Feng, 2002; Alberti *et al.*, 2003). There are an abundance of literatures concerning the complex interactions between urban development and sustainable water utilization. It is commonly acknowledged that urban land expansion has noticeable impacts on regional hydrological environments (Klocking and Haberlandt, 2002; Atef and Rakad, 2003; Carter *et al.*, 2005). An analysis of the change in China's urban population density during the period 1986–l996 shows that urban development and land use demonstrate a trend of basically similar growth (Zhang and Liu, 2001). An interactive mechanism between urban, economic and ecological thresholds for water and land resources facilitates the change from extensive to intensive utilization patterns of these resources during the process of urbanization (Zheng and Feng, 2002; Bao *et al.*, 2006; Bao and Fang, 2009). Scholars worldwide have carried out a series of studies to promote the efficient use of urban water and land

Received 2011-09-15; accepted 2012-01-28

*Corresponding author: Jun LEI (E-mail: Leijun@ms.xjb.ac.cn)

resources. Studies outside of China have concentrated in the areas with high economic values, rapid urbanization or fragile ecology (Ruth and Appasamy, 2001). Chinese researchers primarily focused on metropolitan interlocking areas and the Hexi Corridor (Fang *et al.*, 2004; Fang and Li, 2004; Fang and Sun, 2005; Fang *et al.*, 2007; Fang and Xie, 2010; Bao and Fang, 2007, 2008).

Oasis development and its benefit is one of the major research topics in urban geography in China. Growing populations and rapid urbanization have exacerbated water shortage challenges in arid and semi-arid regions. As regional centers and growth poles, oasis urban areas exert influences that are far beyond their spatial dimensions, and water-land resources are the most critical factors that determine oasis survival and evolution (Ma *et al.*, 2002; Yang *et al.*, 2010a). The effects of oasis urban development on water and land resources are very complex. Existing studies are incapable of fully explaining related interactive mechanisms. Many researchers hold that water resources are a restrictive factor in urban development in arid regions. However, this does not explain the general regularity of arid urbanization (Zhang, 1993). This paper describes a case study of the interactions between oasis urban development and water-land resources at the north slopes of the Tianshan Mountains in Xinjiang, which has certain theoretical significance in helping to realize an optimal allocation of land and water resources in oasis areas.

1 Study area

The study area lies at the northern slopes of the Tianshan Mountains in Xinjiang Uygur autonomous region, China. It is a belt between the northern slopes of the Tianshan Mountains and the southern edge of the Junggar Basin. It starts at Mori county in the east and ends at Wenquan county in the west, ranging from 79°53′E to 92°19′E and 42°45′N to 46°08′N, with a total area of 150,150 km^2 (9% of that of Xinjiang). According to geomorphologic features, the area can be divided into three ecological parts: (1) northern Tianshan Mountains; (2) central oasis; and (3) southern desert (Xi *et al.*, 2005). There are 17 cities/counties in the area, including 2 prefecture-level cities (Urumqi and Karamay), 7 county-level cities (Changji, Fukang, Wujiaqu, Shihezi, Usu, Kuitun and Bole) and 8 counties (Mori, Qitai, Jimsar, Hutubi, Manas, Shawan, Jinghe and Wenquan) (Fig. 1). In 2009, the population in this area was 5.95×10^6, accounting for 27.57% of the total population in Xinjiang. The level of urbanization was up to 67.66%, far higher than the average level in Xinjiang, which was 43%. The regional GDP was 135.79×10^9 RMB yuan, 37.15% of Xinjiang's total.

The study area faces a water shortage. Rivers and lakes are the main surface water supplies in this area

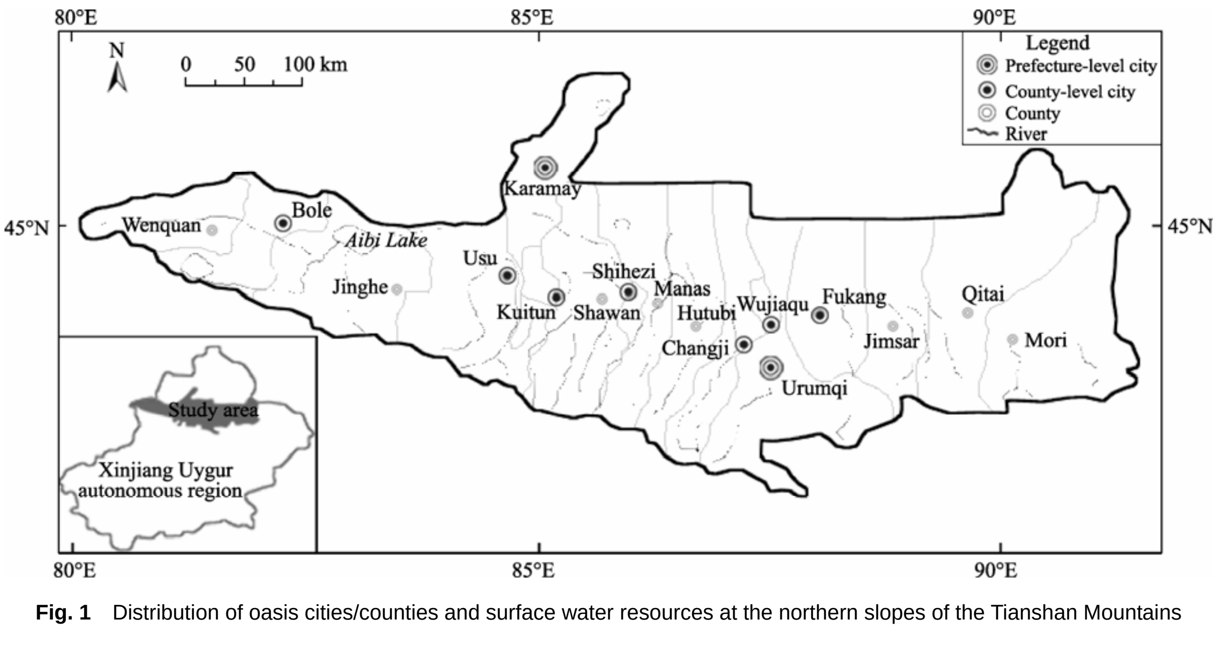


Fig. 1 Distribution of oasis cities/counties and surface water resources at the northern slopes of the Tianshan Mountains

to maintain oasis ecology. Precipitation, glacier melt water and groundwater are the main water sources. The land resources are rich, with a per capita arable area of 0.0307 km^2, higher than the average level of Xinjiang, which is 0.0287 km^2. However, low organic content and high salinity in the soils are major constraints to land utilization in this area. Land and water resources development have remarkable influences on urbanization. On the one hand, rapid urbanization leads to the expansion of urban construction, accelerated adjustment of industrial structures, and the exploitation of energy and mineral resources, all which significantly increase the needs for water and land (Dong *et al.*, 2011a). On the other hand, water and land resources are limited and unevenly distributed within the area, and their supply is unable to meet the increasing demands of urbanization. Due to the recent large-scale development in Xinjiang, the constraints of water-land resources at the northern slopes of the Tianshan Mountains become increasingly serious, affecting the development of oasis urbanization.

2 Data and methods

The statistical data are obtained from Xinjiang Statistical Yearbooks and Xinjiang City and County Construction Statistical Yearbook*s* for years 2000–2009. For data consistency, Wujiaqu is excluded. According to the developmental stages and economic statuses of the studied objects, we selected year 2000, 2005 and 2009 as the periods for analysis.

2.1 Land resources benefit

With the single index "GDP per unit land area", this article analyzes the land resources benefit:

$$f(x)=G_i/S_{ai}. \quad (1)$$

Where, $f(x)$ is land resources benefit; S_{ai} is the actual used land area, or the total of agriculture and construction land; and G_i is the GDP for each unit of land to be assessed.

2.2 Water resources benefit

The total water supply of different cities/counties is adopted to analyze the water resources benefit:

$$f(x)=G_i/S_{ai}. \quad (2)$$

Where, $f(x)$ is water resources benefit, which is defined as the total value of goods and services that water supply brings about within a certain time period; S_{ai} is total water supply; and G_i is the GDP for each unit of land to be assessed.

2.3 Coupling degree model

In order to establish the evaluation indicator system of the coupling between urban development and water-land resources, the effectiveness function of urban water-land resources is introduced. Variable u_i (i=1, 2, …, m) is set as the order parameter of urbanization and water-land resources system; u_{ij} is the j indicator of i order parameter and its value is x_{ij} (1, 2, ..., n); α_{ij} and β_{ij} are respectively upper and lower limits of the order parameter on the critical point of system stability (Liu and Song, 2005). Thus, the orderly efficiency coefficient u_{ij} of urbanization and water-land resources system can be expressed as:

$$u_{ij}=\begin{cases}(x_{ij}-\beta_{ij})\ /(\alpha_{ij}-\beta_{ij})u_{ij}\\(\alpha_{ij}-x_{ij})\ /(\alpha_{ij}-\beta_{ij})u_{ij}\end{cases}. \quad (3)$$

Where, u_{ij} refers to the efficacy contribution of variable x_{ij} to the system. The efficacy coefficient as constructed by the formula reflects the level of objective satisfaction achieved by each indicator. If u_{ij} is close to 0, it means "the most dissatisfied"; and u_{ij} is close to 1, it means "the most satisfied". So, $0\leqslant u_{ij}\leqslant 1$.

The method of coupling degree is used to reveal the interactive coupling between the two subsystems of urban development and water-land resources. The coupling degree reflects the consistence of the systems. A small relative deviation coefficient means a high coordination between the systems. Based on the concept of capacity coupling and the coefficient model of capacity coupling in physics (Liu *et al.*, 2005; Wang and Chen, 2008), the coupling model of interaction between two systems is formulated as follows:

$$C_n=\{(u_1.u_2,\cdots u_m)/[\prod(u_i+u_j)]\}^{1/n}, \quad (4)$$

which facilitates the analysis, by providing the coupling function of urbanization and water-land resources benefit:

$$C=2\{(u_1.u_2)/[(u_1+u_2)(u_1+u_2)]\}^{1/2}. \quad (5)$$

The value of coupling degree C is between (0, 1). If C is close to 1, the coupling degree is at its maximum value. Positive resonance coupling is achieved between the systems or between elements within the systems, and the systems will tend to show a new orderly structure (positive emergence occurs). If C is close to 0, the coupling degree is extremely small, which indicates little relationship between the systems or between elements within the systems, and the systems will develop in a disorderly way (negative emergence appears). In this paper, if $0<C\leqslant 0.25$, urban development and water-land resources development are at a low coupling phase; if $0.25<C\leqslant 0.5$, urban development and water-land resources development are at an antagonism phase; if $0.5<C\leqslant 0.75$, urban development and water-land resources development are at a run-in phase, both being healthy coupling; and if $0.75<C\leqslant 1$, urban development and water-land resources development are at a mature phase, and they synchronously enter a high level of coupling phase.

3 Coupling characteristics between urban development and water-land resources

3.1 Response of population and economic scales to water and land resources consumption

Non-agricultural population growth and GDP changes are important indicators to measure the level of urbanization. Water supply and total built-up area changes can reflect the relationship between urban population growth, economic development and consumption of water-land resources. In this paper, non-agricultural population, GDP, total water supply and built-up area changes were selected to analyze the correlation between them. By linear analysis (Fig. 2), it can be found that the correlation coefficient between non-agricultural population and built-up area is 0.714, and their correlation is not strong. Meanwhile, the correlation coefficient between GDP and built-up area is 0.938. The correlation coefficient between water supply and GDP is only 0.119, and the correlation coefficient between water supply and non-agricultural population is only 0.011, indicating that total water supply does not significantly change with the expansion of non-agricultural population and total GDP growth. The growth rate of total water supply is significantly slower than the growth rates of economy and population, and the correlations between population and built-up area are significantly larger than the correlations for total water supply, which indicates the fact of limited water-land resources for oasis urban development in arid regions.

3.2 Correlation between per capita water resources and urbanization level

It is quite difficult to obtain the data for total water

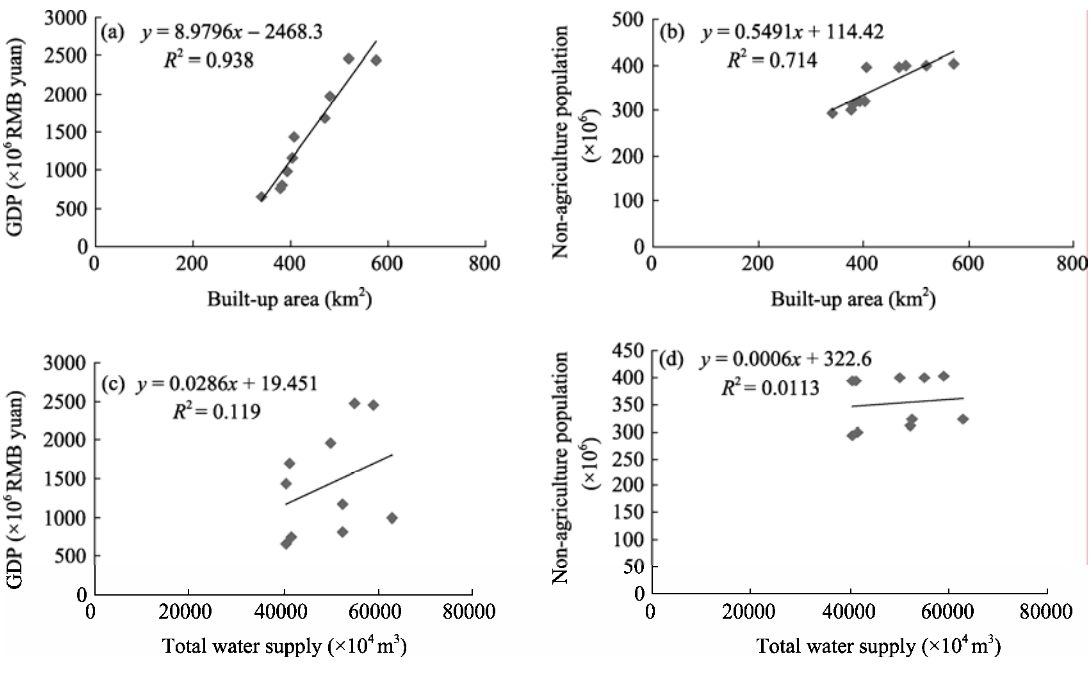


Fig. 2 The correlation between built-up area and GDP (a), built-up area and non-agriculture population (b), total water supply and GDP (c), total water supply and non-agriculture population (d) in the study area during 2000–2009

resources and water consumption of individual cities/counties. Therefore, the two indicators of per capita water supply and per capita built-up area were selected to assess the change of water-land resources use at the northern slopes of the Tianshan Mountains.

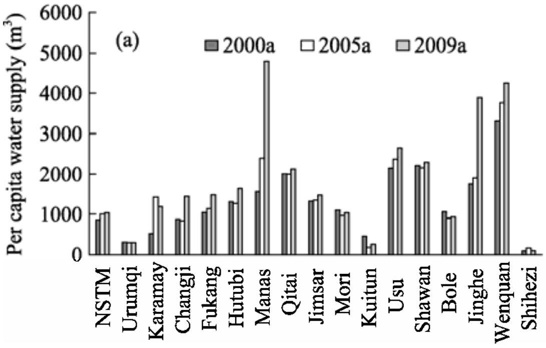
As can been seen in Fig. 3, per capita water supply is less than 300 m^3 in Urumqi and Kuitun; less than 100 m^3 in Shihezi; and the values for the other places are variable. The overall changes in the per capita water supplies and built-up areas for the whole study area during the period 2000–2009 are quite moderate, but the changes among individual cities/counties are significant. Per capita water supply increased by 169 m^3 during the study period. It increased by 141 m^3 in 2000–2005, slowed down in 2005, and then increased by only 29 m^3 in 2005–2009. As for individual cities/counties, it decreased by 13 m^3 in Urumqi, and reduced by 69 m^3, 130 m^3 and 191 m^3 in Mori, Bole and Kuitun, respectively. But the largest increase occurred in Manas and Jinghe, reaching more than 2,000 m^3. In Karamay, Changji, Fukang, Hutubi and Usu, the increases are about 500 m^3. As the level of urbanization increases over time, per capita water supply does not simply increase or decrease in a straight manner, which means the linear relationship is not prominent.

3.3 Correlation between per capita built-up area and urbanization level

Oasis is the core of urban development in arid regions. Urban scale is much smaller in oases than in other parts of China due to the impact of oasis areas and the limit of population sizes. The per capita built-up areas are within 0.03–0.09 km^2 except in Karamay (0.21 km^2), and the spatial differences are small. During the study period, growth or reduction rates of per capita built-up areas were small; per capita construction land areas in Jimsar, Mori, Kuitun, Bole, Wenquan, Jinghe and Shihezi have reduced slightly because of the constraints of urban land and population growth, and those for the remaining cities/counties have increased, but at a low rate.

The scatter plot of the correlation between urbanization level, per capita water consumption and per capita built-up area at the northern slopes of the Tianshan Mountains (Fig. 4) shows: (1) per capita water supplies in the cities/counties with higher urbanization levels are the lowest; (2) the level of urbanization in the cities/counties with higher per capita water supplies are in the middle; and (3) per capita water supplies for the majority cities/counties are between 1,000–2,000 m^3. It can be seen that the per capita built-up areas in most cities/counties are at a low level, being concentrated between 0.02–0.07 km^2. The per capita built-up area and urbanization level in Karamay are higher than those in all the other cities/counties; and Urumqi comes second. Generally speaking, the correlation between urbanization level and per capita built-up area is not significant.

As a whole, the increase of urbanization level has little effect on per capita construction land, and the consumption of water and land resources increases along with the increase of urbanization. The expansion performance of per capita water resource consumption and per capita built-up area, however, is not consistent. It shows a trend of gradual growth, while the per capita built-up area shows a trend of progressive decline, indicating that the construction land consumption at the northern slopes of the Tianshan Mountains is not strong during the process of urbanization, which is different from the situations in East China (Tan *et al.*, 2005).



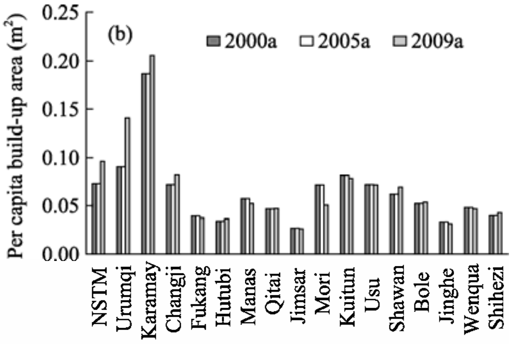


Fig. 3 Changes of per capital water supply (a) and built-up area (b) in the study area. NSTM, the northern slopes of the Tianshan Mountains

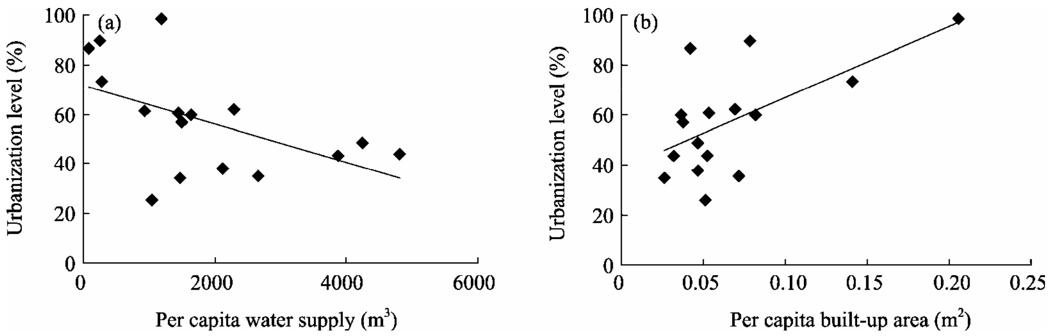


Fig. 4 The correlation between urbanization level and per capita water supply (a) and per capita built-up area (b) in the study area in 2009

3.4 Temporal variation of the coupling degree between urbanization level and water-land resources benefit

According to calculations based on Eqs. 1–5, it can seen that the coupling degrees between water-land resources benefit and urbanization for the period 2000–2009 go downward. The coupling degrees between cities/counties of various scales are different. In 2009, Urumqi, Karamay and Shihezi had high degrees of coupling; Changji and Kuitun were in an adjustment phase; Fukang was in an antagonistic phase; and all the other cities/counties were at low levels of coupling. The result shows that when both urbanization level and water-land development level are low, an overall low level of coupling is present (Table 1).

Table 1 Coupling degrees for different cities/counties

Cities/counties	Year		
	2000	2005	2009
Urumqi	0.9386	0.9301	0.9246
Karamay	0.8877	0.9999	0.9544
Changji	0.8745	0.7174	0.8451
Fukang	0.1578	0.9915	0.1922
Hutubi	0.2969	0.9134	0.5157
Manas	0.8363	0.6190	0.8205
Qitai	0.9660	0.1350	0.6317
Jimsar	0.0914	0.7940	0.3639
Mori	0.2305	0.6360	0.6513
Kuitun	0.9476	0.0365	0.7500
Usu	0.9298	0.9796	0.7753
Shawan	0.8837	0.8402	0.9953
Bole	0.8823	0.7866	0.6724
Jinghe	0.9056	0.1650	0.1906
Wenquan	0.7302	0.8082	0.3458
Shihezi	0.3431	0.8831	0.9937

In recent years, the leading role of Urumqi as a core city has been limited, and the coupling degree of the city has not significantly improved. Limited land and water resources make the coupling degree in the study area show an overall decreasing trend, though slight. This indicates that, in the process of urbanization, the regulation between water-land resources and urban development still needs to be strengthened. It is essential to decide on: (1) a coordinated industrial structure; (2) a planned economic development path; and (3) an aim of regional economic collaboration. Sustainable development can be achieved only when the relationship between the above three is harmonized.

4 Overall characteristics of the coupling between oasis urban development and water-land resources

4.1 Dependence of oasis urban development on the spatial distribution pattern of water-land resources

Due to the unique natural conditions in the arid study area, the location of most human settlements relies on the distribution of rivers and lacustrine water systems. The current distribution pattern of oasis cities/counties at the northern slopes of the Tianshan Mountains is a result of development and evolution over a long history. The direct dependence of oasis urbanization on water resources has been relatively weakened, but it is the impact of water resources on early urban development that has laid the basic pattern of modern urbanization in Xinjiang (Zhang, 1993; Dong *et al.*, 2011b; Zhang and Lei, 2006; Yang *et al.*, 2010b). There are more than 570 rivers and over 100 lakes in

Xinjiang. The amount of water per unit area in North Xinjiang is 2.6 times that in South Xinjiang. The number and scale of cities/counties are much larger in North Xinjiang than in South and East Xinjiang. Among the 21 cities, for example, 10 are seated around the Junggar Basin in North Xinjiang, and only 5 lie around the Tarim Basin in South Xinjiang. Due to the situations of population, economic development and the layout of transportation networks in North Xinjiang, cities/counties are mainly located at the northern slopes of the Tianshan Mountains, distributed in a beaded manner along the zone with most abundant light and water-land resources. If we drew a straight line from Hotan to Mori to divide Xinjiang into two equal halves, only two cities would be found in the eastern part, with the rest in the western part. The oases at the northern slopes of the Tianshan Mountains are scattered near rivers and deserts. Oasis distribution specifically depends on the spatial distribution pattern of water sources. Thus, the evolution of oasis cities/counties is closely related to the limitation of water resources and land. Oasis cities/counties in the study area sit on alluvial plains, backed by the Tianshan Mountains and facing deserts. They are in a banded distribution structure, and expand both vertically and horizontally, making this area the largest one with high population concentration in Xinjiang. The distribution of water-land resources is consistent with the spatial distribution of oasis cities/counties, and is also the basic support for the birth and development of these human settlements.

4.2 Impact of basin shape on the sizes of oasis cities/counties

Water resources determine not only the spatial distribution but also the sizes of oasis cities/counties. In the deserts and oases at the northern slopes of the Tianshan Mountains, water shortage is a severe problem. The oases are separated into relatively independent units by deserts and Gobi. Therefore, dense and mutually supportive city groups cannot be formed to achieve a city-scale agglomeration. Instead, a spotty, lumpy distribution of medium- and small-sized cities comes into being as a result of the limited carrying capacity and spatial distribution of water resources. With the exploitation of featured natural resources, a number of new cities/counties will gradually take shape, but due to the constraint of water resources and terrain conditions in the study area, both their geographic distribution and sizes will be restricted over a certain period of time. Karamay, for instance, relies on a water diversion project to solve its water shortage and expand its urban area. Its modern urban scale develops in step with the continuous development of regulated water conservancy in the artificial oasis that it sits on.

4.3 Effect of water-land resources integration on urban growth

The improvement in the urbanization levels of oasis cities/counties affects the changes in water resources development. The most direct reflection is the integration and efficiency of water-land utilization, which is significantly higher than that in non-urban areas. It can be seen from the above analysis that the growth of total water supply and built-up area caused by the development of oasis cities/counties is not rapid. Only large cities such as Urumqi face the conflict between urbanization and water-land resources at a certain developmental stage. The improvement in urbanization level promotes the utilization efficiency of oasis water-land resources, which, in return, leads to a fundamental impact on urban population, industrial agglomeration, as well as the scale and structure of urban systems. With the expansion of urban areas, the effect of urban scale becomes evident, promoting concentrated development of oasis land and united supply of water resources, and meanwhile, boosting the integration of both.

4.4 Impact of land and water resources development on regional spatial structure

Oasis cities/counties take a central function as growth poles within the study area. Their leading roles, however, are limited and the levels of urbanization are lower than in other parts of China. This is mainly owing to local water shortages. The oasis distribution is patchy in the deserts, and the cities/counties are distributed in different river basins, where the spatial pattern of water resources largely determines the current form of urban development. Oasis boundaries constitute natural barriers to external urban radiation and hence limit the sizes of the cities/counties. Research shows that the living and production consumption in Xinjiang has been increasing since 2000, which exacerbated the shortage of urban water resources and, as a result, profoundly affected future urban expansion (Zhang and Lei, 2006). Urban construction converges within oasis centers. The spatial growth of oases determines the extent of land for construction, and the expansion of oasis urban areas is relatively slow at the northern slopes of the Tianshan Mountains. There are large differences between the rates of expansion in geographical area for different cities/counties of various scales, which is not consistent with the circumstances in mainland China.

4.5 Decreased impact of land and water resources on oasis urban development

From the point of view of the coupling changes, the coupling degree between urban development and water-land resources at the northern slopes of the Tianshan Mountains has shown a downward trend since 2000. The degree of the decrease is not large, but it demonstrates that the role of water-land resources in modern urban development is different from the past (Zhang, 2002). Based on the analysis of coordinated coupling between each city/county and the water-land resources in the study area, it shows that the coupling degree of water-land resources is far higher in cities/counties with high levels of economic development than in those with low urbanization levels. The evolutional advance of oasis cities/counties promotes the agglomeration and utilization efficiency of limited water-land resources. Lu (2003) points out that the role of natural resources in China's economic growth is becoming less influential. The analysis in this paper also proves that, with the growth in urbanization level, economy is developing faster than ever before. However, an accompanied rapid growth in total water supply has not occurred, and the substitution of water-land resources for other inputs is transforming the model of economic development into one with relatively less use of water-land resources, relieving the increasing scarcity of these resources (Romer, 2001). Certainly, this conclusion requires further research by incorporating multiple indicators.

5 Conclusions

Based on a case study at the north slopes of the Tianshan Mountains, our research provides an understanding of the relationship between the development of oasis cities/counties and the utilization of available water-land resources by selecting the two single elements of total water supply and built-up area.

Although our evaluation helps to directly and clearly analyze the coupling degree among selected elements by ignoring the interference of other factors, it is comparatively simple and may not be able to reveal deeper interactive mechanisms. Rigorous efforts have thus to be made to assess how water-land resources and related wastes will impact urban development in oasis areas, and to develop new ideas and innovative technologies for the sake of sound practices in guiding rational regional development.

Acknowledgments

This work was supported by the Dr. Western-funded Projects of Chinese Academy of Sciences (XBBS200805) and the National Natural Science Foundation of China (40901092).

References

Alberti M, Marzluff J M, Shulenberger E, *et al*. 2003. Integrating humans into ecology: opportunities and challenges for studying urban ecosystems. Bioscience, 53(12): 1169–1179.

Atef A K, Rakad T. 2003. Influence of urbanization on water quality deterioration during drought periods in South Jordan. Journal of Arid Environments, 53(4): 619–630.

Bao C, Fang C L, Fan C. 2006. Mutual optimization of water utilization structure and industrial structure in arid inland river basins of Northwest China. Journal of Geographical Sciences, 16(1): 87–98.

Bao C, Fang C L. 2007. Water resources constraint force on urbanization in water deficient regions: a case study of the Hexi Corridor arid area of NW China. Ecological Economics, 62(3–4): 508–517.

Bao C, Fang C L. 2008. Temporal and spatial variations of water resources constraint intensity on urbanization in arid area. Acta Geographica Sinica, 63(11) : 1140–1150.

Bao C, Fang C L. 2009. Integrated assessment model of water resources constraint intensity on urbanization in arid area. Journal of Geographical Sciences, 199(3): 273–286.

Carter N, Kreutzwiser R, de Lo R. 2005. Closing the circle: linking land use planning and water management at the local level. Land Use

Policy, 22: 115–127.

Chan R C K, Yao S M. 1999. Urbanization and sustainable metropolitan development in China: patterns, problems and prospects. GeoJournal, 49(3): 269–277.

Dong W, Deng F, Yang Y. 2011a. Development and spatial effect of resource-based industries in Urumqi. Geographical Research, 22(3): 261–271.

Dong W, Yang Y, Zhou Y. 2011b. Land use change and evaluation of land use efficiency in an arid oasis city: a case of Urumqi, China. Arid Land Geography, 34(4): 679–685.

Fang C L, Bao C, Shen Y M. 2004. Analysis on the characteristic and the change trend of urban expansion restricted by water resources in the arid area of Northwest China—a case study of the cities in the Western Long Hai-Lan Xin Economic Zone. Journal of Natural Resources, 19(2): 248–256.

Fang C L, Li M. 2004. Urbanization mode with the restraint of water resource in Hexi Corridor arid area of Northwest China. Geographical Research, 23(6): 825–832.

Fang C L, Sun X L. 2005. Coupling effects between water resources change and urbanization process in Hexi Corridor of Northwest China. Resources Science, 27(2): 2–9.

Fang C L, Bao C, Huang J C. 2007. Management implications to water resources constraint force on socio-economic system in rapid urbanization: a case study of the Hexi Corridor, NW China. Water Resources Management, 21(9): 1613–1633.

Fang C L, Xie Y. 2010. Sustainable urban development in water-onstrained western China: a case study along the mid-section of silk road–Hexi Corridor. Journal of Arid Environments, 74(1): 140–148.

Klocking B, Haberlandt U. 2002. Impact of land use changes on water dynamics. Physics and Chemistry of the Earth, 27(9–10): 619–629.

Liu Y B, Li R D, Song X F. 2005a. Grey associative analysis of regional urbanization and eco-environment coupling in China. Acta Geographica Sinica, 60(2): 237–247.

Liu Y B, Song X F. 2005b. Grey associative analysis of regional urbanization and eco-environment coupling in China. Journal of China University of Minin & Technology, 34(1): 91–96.

Lu D D. 2003. New factors and new patterns of regional development in China. Geographical Research, 22(3): 261–271.

Ma X W, Li B G, Cheng Y. 2002. Quantitative research on the temporal and spatial change of water and land resources. Arid Land Geography, 25(2): 109–114.

Romer D. 2001. Advanced Macroeconomics. 2nd ed. New York: McGraw-Hill, 30–38.

Ruth M D, Appasamy P P. 2001. Urbanization and Intersectional Competition for water. Urbanization and Water, 47 (1): 27–51.

Statistics Bureau of Xinjiang Uygur Autonomous Region. 2005. Fifty years in Xinjiang. Beijing: China Statistics Press.

Statistics Bureau of Xinjiang Uygur Autonomous Region. 2001–2009. Xinjiang Statistical Yearbooks. Beijing: China Statistics Press.

Tan M H, Li X B, Lu C H. 2005. Urban land expation and arable land loss of the major citiesa in China in the 1990s. Sciences in China: Series D, 48(9): 1492–1500.

Wang Q, Chen C. 2008. Coupling degrees of industrial cluster and economic space of region. Scientia Geographica Sinica, 28(2): 145–149.

Xi C, Ge P L, Jun X, Ke F Z, *et al.* 2005. Ecological response to the climate change on the northern slope of the Tianshan Mountains in Xinjiang. Science in China: Series D, 48(6): 765–777.

Yang Y, Zhang X L, Lei J, *et al.* 2010a. Sustainable regional development based on resources exploitation and utilization. Scientia Geographica Sinica, 30(3): 363–369.

Yang Y, Zhang X L, Lei J, *et al.* 2010b. Spatial integration of oasis city group around the western margins of the Tarim Basin. Journal of Arid Land, 2(3): 214–221.

Zhang W Z, Liu Y S. 2001. Study on land resource problems and countermeasures in the process of urbanization China. Regional Views, 14: 1–8.

Zhang X L. 1993. Regional evolution of towns in the Tarim Basin. Arid Land Geography, 16(4): 51–57.

Zhang X L. 2002. Influence of desert mineral resource exploitation on the spatial structure of the urban system. Sciences in China: Series D, 45(Supp1.): 180–184.

Zhang X L, Lei J. 2006. Trend of urban system structure under the restriction of water and land resources in Xinjiang. Chinese Science Bulletin, 51(5): 179–188.

Zheng Y, Feng D X. 2002. An analysis of urbanization process and water-land resource sustainable utilization. Progress in Geography, 21(3): 223–229.