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Original Research Paper

Change in Water Consumption and its Effect on the Land Cover of the Oasis in the Tarim River Basin, Xinjiang, China

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ABSTRACT

Water resources have major effects on the temporal and spatial distribution of land use in oases and arid regions. To determine the response relation between water consumption and the land use of the oasis in the Tarim river basin, Xinjiang, China, we conducted a study analyzing the temporal and spatial synchronization in this basin by employing hydrological data, land-use maps (for 2000, 2005, and 2010), and the spatial analysis tool ArcGIS. Results show that the water consumption in the Tarim river basin fluctuated noticeably from 2000 to 2010 and was mainly concentrated in July. A close relationship was established between land-use type and water body, and the range of land fluctuation was related to the distance between these two variables. A turning point was observed two kilometers from the land site to the water body for most land-use types. The dynamic degree of unused land, forest land and grassland decreased continuously, whereas that of cultivated land, farmland and residential land increased continuously. The increase and decrease were primarily concentrated in the cultivated and unused lands, respectively. These findings also have implications in the exploration of water resources management, changing water consumption and its effects on the land use of oasis in Tarim river basin.

INTRODUCTION

Oases have become core areas of human activities as special landscapes in arid regions (Zhai et al. 2004, Xu et al. 2011). These landscapes strongly depend on surface runoff because of the heavy evaporation and the scarcity of rainfall in these areas (Liu et al. 2011, Ling et al. 2013). The available water resource is the main limiting factor in the ecological balance and the land use in oases (Mekki et al. 2013), and the relationship between this resource and oases has been studied extensively (Fan et al. 2013, Zhou et al. 2011, Xu et al. 2013).

The temporal and spatial distribution of surface water resources significantly influence the evolution of land use (Shahram et al. 2011). Previous studies report a positive relationship between land-use changes and water resources (Frank et al. 2000, Tong et al. 2012, Prasetyo et al. 2013, Beate et al. 2002). In addition, the efficiency of water resource utilization can alter the rates of land-use transformation (Baker 2003). A close relationship has also been established between water distribution and land-use type in the Tarim river basin, which is a typical inland river basin in the arid region of China (Li et al. 2004).

The effects of shifts in water consumption and of land use and land cover change (LUCC) have become popular topics in this field (Chang et al. 2005, Gan et al. 2003, Jia 1996). Over the past 20 years, many achievements have been presented regarding runoff generation and confluence, water resource use, ecological evolution, and environmental protection in the Tarim river basin (Fu et al. 2010, Sun et al. 2013, Zhao et al. 2009, Zhao et al. 2010). However, research on the response relationship between runoff change and LUCC remains scarce. The present study fills the research gap by examining the response relationship between the temporal and spatial distributions of surface water resources and LUCC.

OVERVIEW OF THE STUDY AREA

The study area is the mainstream watershed of the Tarim River, Xinjiang, China, which is located at the northern margin of the Taklimakan Desert and covers a surface area of approximately 37780 km^2 between latitudes 39°21'-41°30' N and longitudes 80°542'-88°30'E (Fig. 1). The climate in this area is extremely dry and rainfall is scarce; the average annual precipitation ranges between 20 and 70 mm, the average annual temperature is between 10°C and 11°C, and the mean annual potential evaporation is between 2000 and 3000 mm. The annual average flow is 27.86m^3 × 10^{8}m^3 (Yan et al. 2008, Sun et al. 2013, Li et al. 2001). Moreover, the main land-use types in the area include cultivated land,

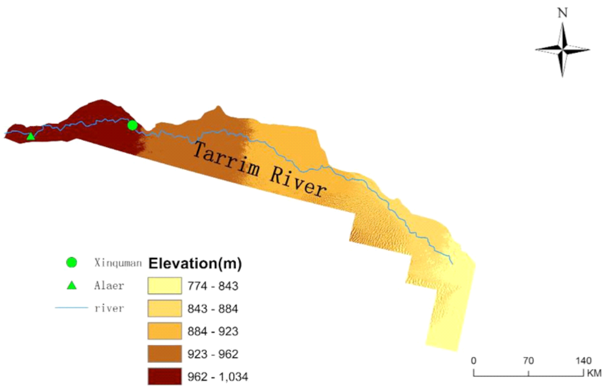

Fig. 1: The study area in Tarim River Basin, Xinjiang, China.

woodland and unused land, which occupy 95.63% of the total river area. Unused land, which mostly comprises of desert lands, accounts for 68.19% of the study area.

MATERIALS AND METHODS

Data collection: The land-use maps for 2000, 2005 and 2010 were interpreted on the basis of the TM images according to the land classification system of remote sensing monitoring for China (Yan et al. 2008, Zhang et al. 2006). These maps were obtained from the Xinjiang Institute of Ecological and Geography, Chinese Academy of Sciences. Six land types were identified in the study area, namely, farmland, forest land, grassland, wetland, urban and rural residential lands, construction land and unused land. Daily flow data from January 1, 2000 to December 31, 2010 were derived from the two hydrological stations (namely, Alaer and Xinquman) by the Tarim River Basin Management Bureau. The drainage map (1:250000) was obtained from the State Bureau of Surveying and Mapping.

Dynamic degree of land use: We introduced the single dynamic degree to obtain information on land use transition in different periods (Wang et al. 2010). This degree indicates the quantitative changes in a certain land type within a period, in addition to describing the speed of this change and the difference in the types of land. The dynamic degree of land use can be expressed as follows:

$$K = \frac{Ub - Ua}{Ua} \times \frac{1}{T} \times 100\% \quad ...(1)$$

Where k denotes the dynamic degree of land use for a certain type of land, Ua and Ub represents the quantity of land-use types in the early and late stages, respectively, and T denotes the study period. If T represents a year, then k denotes the annual change rate of land use.

Buffer analysis: A buffer analysis was conducted to identify the areas that surround a water body (Wang et al. 2010, Li et al. 2009). A buffer with a distance of 18 km was generated around the river or reservoirs and was then used to analyze the spatial response between surface water and land-use change. This analysis was performed by using the spatial analysis module in ArcGIS.

RESULT ANALYSIS

Change in Water Consumption

The water consumption levels at the Alaer and Xinquman sections were calculated according to the flow data from 2000 to 2010. Given that lateral recharge occurs in a small portion of the study area, the total water consumption was computed according to the difference in flow between the two sections. The annual and monthly changes in water consumption are illustrated in Figs. 2 and 3 respectively.

Fig. 2 indicates that the water consumption in the study area ranges from $3.61 \times 10^8 m^3$ to $16.99 \times 10^8 m^3$ during the period from 2000 to 2010. The peak consumption was observed in 2007, while the lowest consumption was detected in 2010. Water consumption fluctuated smoothly before 2007 but decreased rapidly after that year.

Fig. 3 displays monthly water consumption as a single peak curve. The main consumption periods were distributed throughout the months from June to September. The total consumption in these three months was $8.13 \times 10^8 m^3$, which accounted for 72.98% of the total consumption throughout the entire year. The peak value, which accounted for 28.3% of total water consumption, was recorded in July. The water consumption levels in October and November were far lower than those in the other months.

Characteristics of Land-use Change

Temporal and spatial changes in land use: As per the land-use maps of the Tarim river basin in 2000, 2005 and 2010, the characteristics of change were spatially analyzed with a tool in ArcGIS (Fujihara et al. 2005). The results are presented in Figs. 4 and 5.

Fig. 4 suggests that land use changed significantly over the past decade. Such changes affected almost the entire region from 2000 to 2005, although the influence was mostly concentrated on the upper and middle reaches between 2006 and 2010. The change area accounted for 4.03% of the total area.

Fig. 5 shows the fluctuations in the area and in the dynamic degree of each land-use type during the period of 2000 to 2010. In the first period, the farmland exhibited the most significant decrement of -7.37%, the grassland dis-

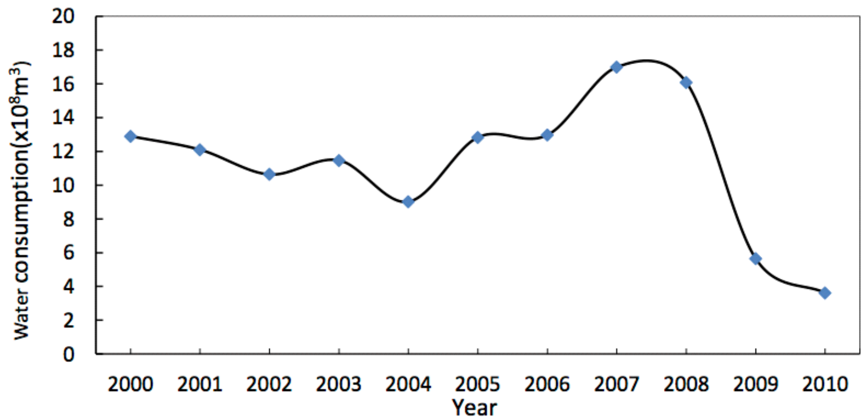

Fig. 2: Annual change in water consumption between the Alaer and Xinquman sections.

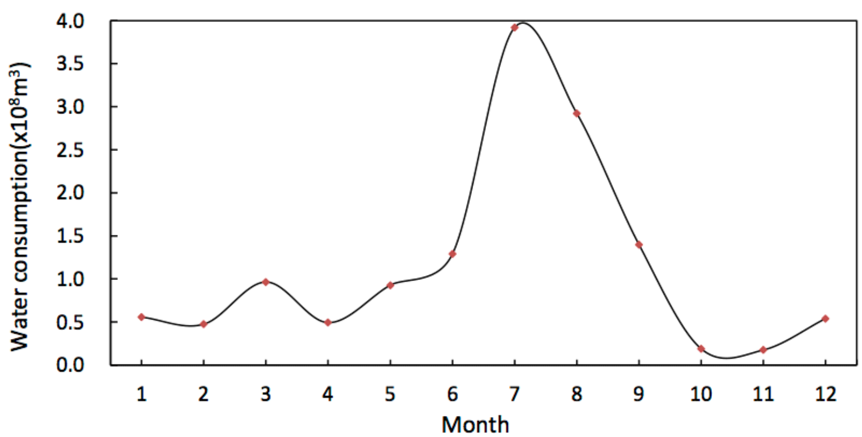

Fig. 3: Monthly change in water consumption between the Alaer and Xinquman sections.

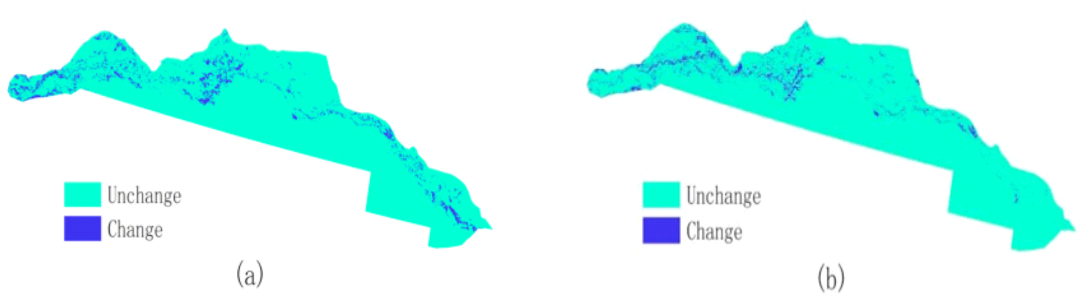

Fig. 4: Spatial change in land use in the Tarim river basin during the period of 2000 to 2010 (a. 2000 to 2005; b. 2005 to 2010).

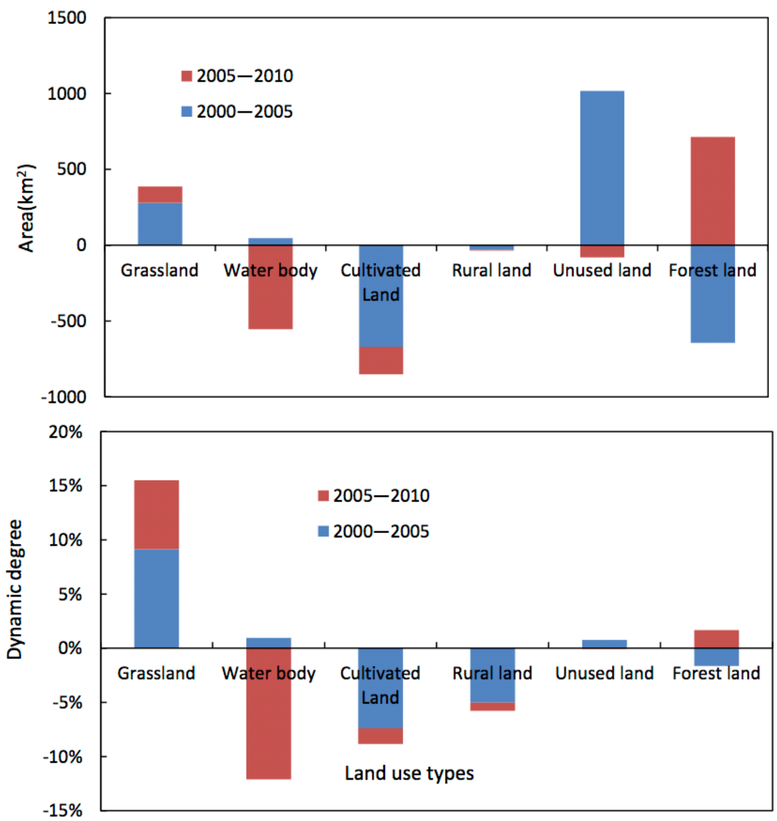

Fig. 5: Temporal change in the land-use types of the Tarim river basin (2000 to 2010).

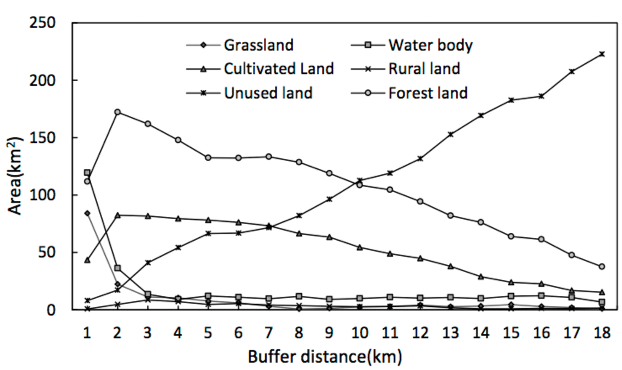

Fig. 6. Change in land use with distance from the water body in the Tarim river basin (2000 to 2010).

played the maximum increment of 9.13%, and the unused land reported the minimum increment of 0.77%. In the second period, grassland exhibited the maximum decrement of -1.68% and the water body displayed the greatest increase range (12.12%).

The continuously decreasing dynamic degrees of unused land, forest land and grassland and the continuously increasing dynamic degrees of the water body, farmland and residential land indicated that the human activities in these areas have aggravated the change in land-use types. These changes were also consistent with the development of each region.

Characteristics of land-use transition: A transfer matrix was generated (Table 4) to analyze the transfer characteristic of land use.

Table 1 shows a significant change in the study area from 2000 to 2010. In the period of 2000 to 2005, 34.88% of the grassland and 3.22% of the forest land were changed into cultivated land, whereas only a small proportion of the original cultivated land was converted into other land types. The change in grassland amounted to 61.82%, which represented the greatest ration of transfer among all land-use types. In the period of 2005 to 2010, the change range of all land-use types decreased, whereas that of the cultivated land continued to increase. Specifically, the change range of grassland

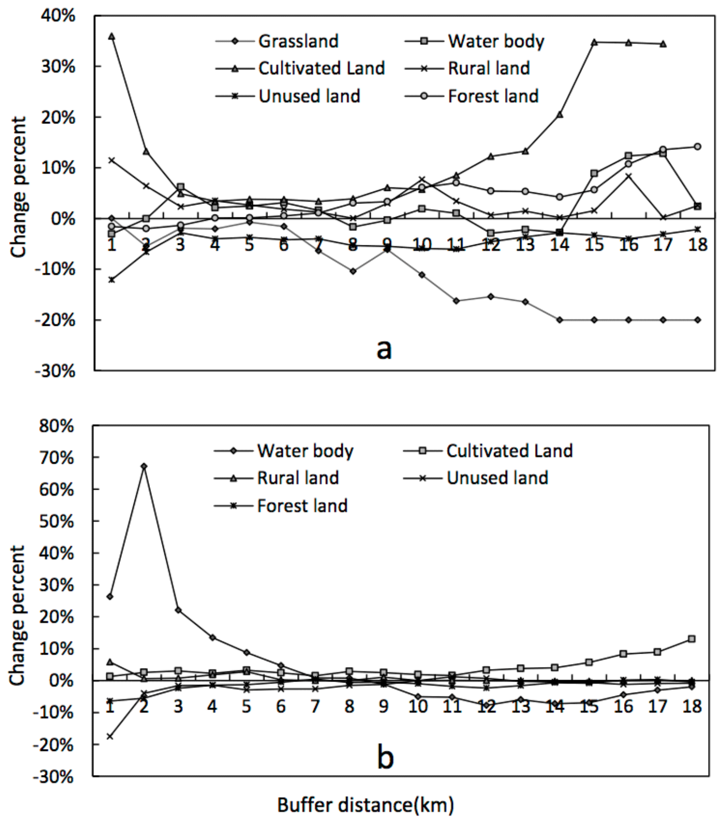

Fig. 7: Relationship of land-use change to distance from the water body (a: 2000 to 2005; b: 2006 to 2010).

and forest land decreased by 48.32% and 10.89%, respectively. Overall, the transfer trends of cultivated and unused lands increased and decreased, respectively, which suggested that an increase in human activities degrades the ecosystem and the environment.

Effect of Surface Water Distribution on LUCC

To analyze the relationship between surface water distribution and LUCC, the spatial distribution of surface water was approximately reflected on the basis of the water body buffer. First, we installed an 18-km buffer between the Alaer and Xinquman sections and then divided the region into 17 parts at intervals of 1-km interval.

Distribution characteristics of land-use type with distance from the water body: The mean of each land-use type was calculated based on the LUCC data for 2000, 2005 and 2010 (Fig. 6).

Fig. 6 depicts a significant relationship between land-use type and distance from the water body. A turning point was observed at 2 km for most land-use types, which indicated an increasing trend (< 2 km) and decreasing trend (2 km to 18 km) for cultivated land, forest land and rural land. Such trends may be attributed to the effect of the distance of the groundwater recharge that was distributed from the river to these areas. The water body and grassland areas shrank with a decrease in distance, whereas the unused land area increased linearly with distance. Among the 18 partial regions, the largest area was the unused land, whereas the smallest area was the rural land.

The analysis results show that the human activities are mainly concentrated at the nearby river in the arid region. The influencing distance also depends on the groundwater recharge. Therefore, an increase in distance denotes a large ecological area.

Land-use change under different water consumption patterns: The water balance method was used to examine the water consumption statistics in the study area, and the average annual water consumption between 2000 and 2005 was $11.49 \times 10^8 m^3$. This value peaked at $11.06 \times 10^8 m^3$ in 2007. To analyze the effect of water consumption on land-use change, the change in each land-use type was calculated for the period of 2000 to 2010 (Table 2).

Table 1: (a) Transfer matrix of land-use types in the Tarim river basin (2000 to 2005) (%).

			2005				
2000	Grassland	Water body	Cultivated Land	Rural land	Unused land	Forest land	Total
Grassland		23.00	34.88	1.47	1.15	1.32	61.82
Water body	9.42		1.69	0.03	1.13	16.27	28.55
Cultivated Land	0.02	0.05		0.37	0.02	0.25	0.70
Rural land	0.00	0.07	0.00		0.00	0.00	0.08
Unused land	0.02	0.16	0.75	0.03		3.05	4.01
Forest land	0.03	0.56	3.22	0.09	0.32		4.22
Total	0.88	2.42	6.58	0.40	67.23	22.49	

(b) Transfer matrix of land-use types in the Tarim river basin (2005 to 2010) (%).

			2005				
2010	Grassland	Water body	Cultivated Land	Rural land	Unused land	Forest land	Total
Grassland		43.00	3.68	0.00	1.37	0.27	48.32
Water body	5.67		0.69	0.02	0.52	2.79	9.69
Cultivated Land	0.06	1.56		0.21	0.98	0.39	3.19
Rural land	0.00	0.02	0.86		0.01	0.06	0.95
Unused land	0.00	0.15	0.21	0.00		0.69	1.05
Forest land	0.01	4.97	2.20	0.02	3.69		10.89
Total	0.60	3.89	7.06	0.42	67.44	20.60	

Table 2: Land-use change types under different water consumption patterns.

Land use types	Change rate (%)	
	2000-2005	2006-2010
Grassland	-17.57	-30.13
Water body	1.95	72.27
Cultivated Land	44.70	17.52
Rural land	16.02	4.39
Unused land	-28.66	-5.91
Forest land	12.20	-10.56

Table 2 shows that the natural vegetation significantly decreased with water consumption during the study period. In the first stage, cultivated land demonstrated the most significant increase among all the land types (44.70%), whereas the unused land shrank by 28.66% (more than the grassland). In the second stage, the grassland was reduced by 30.13% and the proportion of the water body fluctuated considerably by up to 72.27%, closely followed by the cultivated land.

In sum, water consumption, which represents the presence of human activities, strongly affects land-use change by reducing the natural vegetation area and increasing the cultivated land area.

Relationship of land-use change to distance from the water body: To analyze the relationship of land-use change to surface water distribution, the changes to the area of all land-use types were calculated for the 18 partial regions. The statistical periods were divided into two parts, and the results are depicted in Fig. 7.

An increase in distance denotes increased fluctuation in the change range. Primarily, the unused land and grassland decreased, whereas the cultivated land increased the most significantly. The change range fluctuated between -20% and 40% during the period of 2000 to 2005. Moreover, the change ratio for all land-use types, with the exception of cultivated land, was no more than 10% within 10 km. Considerable changes were observed in regions beyond 10 km. The most significant shift was observed in the cultivated land, which followed a decreasing trend within 2 km and then exhibited an increasing trend with distance. The area of grassland decreased in the entire buffer region. The change range fluctuated between -10% and 10% for the period of 2005 to 2010. The fluctuations in the unused land and grassland areas were obvious; the change ratio of unused land peaked at 70% at 2 km before decreasing, whereas that of grassland peaked at 170% at 13 km. This ratio increased significantly between 9 and 14 km.

The changes in the natural vegetation and unused areas are evident as per the afore mentioned analysis. The vegetation area far from the water body has disappeared because of the water shortage, whereas that near the water body has been transformed into cultivated land. Therefore, a distance of 2 km may be used as an influence threshold to examine the change in land use in arid regions with distance from the water body.

CONCLUSIONS

Water consumption in the Tarim river basin has fluctuated considerably over the past few decades. The changes in the land-use types are aggravated by human activities, and the transfer trend mainly indicates an increase in cultivated land and a decrease in unused land. Overall, an increase in human activities degrades the ecosystem.

A clear relationship was observed between land-use type and distance from the water body, and a turning point was recorded at 2 km for most land-use types. The decreasing region was mainly distributed across the unused land and the grassland. The cultivated land increased most significantly, which indicates that human activities are mainly concentrated in the arid areas near the river. In other words, lands that are located far from the river have great ecological value.

A significant spatial relationship was also detected between land-use change and the water consumption patterns. Human activities directly reduce the natural vegetation area and increase the cultivated land area. A 2 km distance might be set as an influence threshold to examine the change in the land-use types in arid regions along with their distance from the water body.

In sum, the ecological condition of a land declines with unreasonable water consumption. The results and method applied in this study may provide a reference for future water resources management and exploration studies.

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