Quaternary International xxx (2014) 1–8

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Land-use conversion and its attribution in the Kaidu–Kongqi River Basin, China

Yang Wang [a], Yaning Chen [b, *], Jianli Ding [a], Gonghuan Fang [b]

[a] *College of Resources and Environmental Science, Xinjiang University, Urumqi, Xinjiang, 830046, China*
[b] *State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, Xinjiang 830011, China*

ARTICLE INFO

Article history:
Available online xxx

Keywords:
Oasis cultivated land evolution
Climate change
Human activities

ABSTRACT

In the past 50 years, the Kaidu–Kongqi River Basin (KKRB) in the arid region of northwest China (ARNC) has experienced drastic climate variability. Meanwhile, from 2000 to 2013, the growths of population and socioeconomic development in the area were drastic, along with much more intensive water management activities. These factors may have caused considerable land use/cover change (LUCC) in the area. Based on the land use/cover classification data derived from the Landsat TM imageries in 1990, 2000, and 2010, as well as the governmental socioeconomic statistics and field observation data, this study investigated the LUCC in the KKRB during 1990–2010. The findings include: (1) The LUCC in the Kaidu–Kongqi River Basin was considerable during the study period, and this change was largely limited to the grassland and cultivated land. The natural grassland in the area decreased with a rate of 118.1 km^2/y, whereas the cultivated land increased with a rate of 79.2 km^2/y. The rapid expansion of cultivated land was mainly sourced from reclamations of wasteland and natural grassland. (2) The LUCC has been resulted from the interaction of natural environmental changes and human activities. The changing runoff affected by climate change has played a fundamental role in land use conversion. The human activity intensity index value rose from 0.75 for 1990–2000 to 0.88 for 2000–2010.

1. Introduction

The past century has been marked by dramatic climate changes including a rising trend of air temperature and altered temporal and spatial patterns of precipitation and also by increasingly intensified human activities leading to drastic changes in Land use/cover change (LUCC) (Fu, 2003; Brovkin et al., 2004; Lioubimtseva et al., 2005; Sulieman and Elagib, 2012; Xu et al., 2013). LUCC and its environmental effects have become a major topic in the global change research since the 1990s (Liu, 1992; Luo et al., 2003; Feddema et al., 2005; Wang et al., 2006; Falcucci et al., 2007; Fang et al., 2013). The interaction between land use/cover determines the regional climate, which has great impact on various ecosystems, from regional to global scales (Briggs et al., 2005; Pyke and Andelman, 2007). LUCC in the arid region of Northwest China (ARNC) is mainly concentrated in the oases along rivers, driven by unique natural and human factors (Luo et al., 2002; Hietel et al., 2005). LUCC is building a bridge between social and natural sciences, and it is clearly an essential component in all considerations of sustainability.

Research that is cross-cutting and regional is important because some of the effects accompanying global change will be most significant at the regional level (Wei, 2000; Li et al., 2012). In this study, we gave LUCC in the Kaidu–Kongqi River Basin (KKRB) during the past two decades, a close examination using satellite imagery data and field investigation data. KKRB is located in the middle part of the ARNC and has a mountain–oasis–desert system that is typical in ARNC. It features fragile ecosystems and sensitive responses to climate variability (Huang et al., 2009; Chen et al., 2012; Chen, 2013). In the past two decades, it has been experiencing a rapid economic development and population growth, leading to increasingly intensive water resource utilization that has resulted in ecological deterioration and landscape fragmentation, endangered the sustainable regional socioeconomic development. KKRB is a typical arid inland basin and mountain–oasis–desert pattern, and it also is a typical composite system. Therefore, land use and land cover change resulted from the interaction of human activity (social and economic factors) and natural climate changes (natural factors).

---

* Corresponding author.
E-mail address: chenyn@ms.xjb.ac.cn (Y. Chen).

http://dx.doi.org/10.1016/j.quaint.2014.10.010
1040-6182/© 2014 Elsevier Ltd and INQUA. All rights reserved.

Please cite this article in press as: Wang, Y., et al., Land-use conversion and its attribution in the Kaidu–Kongqi River Basin, China, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.10.010

In this study, we particularly characterized the changes of farmland and natural grassland in the KKRB as a consequence of the ecological water conveyance project conducted by the government during 1990–2000 that transferred water from the Kongqi River to the neighboring Tarim River. The ultimate and broad objective of LUCC is to improve understanding of, and gain new knowledge on regionally based, interactive changes between land uses and covers, and try to provide scientific basis for the development and protection of land resources in the arid region.

2. Data and materials

2.1. Study area

The Kaidu–Kongqi River system forms a major tributary of the Tarim River, and the latter is the largest inland river of China. The Kaidu–Kongqi River Basin (KKRB), with an area of 7.7×10^4 km^2, is located at the north fringe of the Taklimakan Desert and the south slope of the Tianshan Mountains. It contains the Kaidu River, Bosten Lake, and Kongqi River. Bosten is China's largest inland freshwater lake. The lake is where the Kaidu River ends and the Kongqi River begins (Fig. 1). The terrain of this region features huge mountain ranges, narrow plains where oases are located, and vast desert. The Basin includes five counties (Heijing, Heshuo, Bohu, Yanqi, and Yu li) and a city (Korla). The total population of the KKRB is 108.56×10^4 in 2010, accounting for about 11% of the population of the Tarim River Basin. The GDP of the KKRB in 2010 was 4.69×10^{10} yuan (RMB), accounting for 37.95% of the GDP of the Tarim River Basin in that year.

The region has a typical inner-continental climate, with annual average temperatures of −4.26 °C, 7.9 °C, and 10.5 °C for the mountain, oasis, and desert areas, respectively; and annual average precipitation of less than 500 mm in the mountains, less than 100 mm in the plain, and less than 50 mm at the center of desert. During the period of 1960–2009, the average annual runoff was about 35×10^8 m^3, and the runoff is replenished by snowmelt in spring, sometimes causing floods.

2.2. Materials

We collected monthly runoff data for 1960–2010 from the Dashankou hydrological station, which is in an area with less socioeconomic activities and human disturbance. We collected temperature and precipitation data for the same period from five meteorological stations operated by the China Meteorological Administration, two located in the mountains, two in the oases, and one in the desert. We derived the land use/cover data from TM imageries, including Landsat bands 5, 4, and 3 for August 8, 1990, August 8, 2000, and September 5, 2010. We selected these imageries for their good qualities (without much cloud). Considering the relatively simple land uses and landscapes in the study area, we adopted a six-type classification system used by the Resources and Environment Database of Chinese Academy of Sciences, including water body, cultivated land, forestland, grassland, residential and industrial land, and unused land. The classification was conducted using ENVI and ArcGIS software, augmented by field trips with GPS. Supported by the Landsat TM digital images, this paper established topological relations, generating three land-use graphical data, and analysed the spatial patterns and temporal variation of land-use change in Kaidu–Kongqi River Basin during 1990–2010, especially the expansion of cultivated land reduction of natural grassland. Some attribute data used in the classification came from the "Xinjiang Statistical Yearbook" (Statistical Bureau of Xinjiang Uygur Autonomous Region, 1991–2011).

We evaluated the classification accuracy with a confusion matrix based on 300 random points selected in the study area. We determined the benchmark values for these points using field data, high-resolution images from Google Earth, and combined with three fieldwork accuracy checks. The matrix shows that the classification accuracy of the major types in the area is satisfactory. Specifically, the accuracy of cultivated lands reaches 91.26%; the residential and industrial areas reaches 94%, as well as the water bodies up to 94%; forestland reaches 86.09%; grassland reaches 85.21%; and unused land reaches 88.74%. The total classification accuracy is 92%, and the Kappa coefficient is 0.8277.

2.3. Methods

2.3.1. Trend analysis with the Mann–Kendall non-parametric test

We used the Mann–Kendall test to detect trends in meteorological factors. The Mann–Kendall test is widely used to detect whether a time series has a significant trend or not (Gan, 1998).

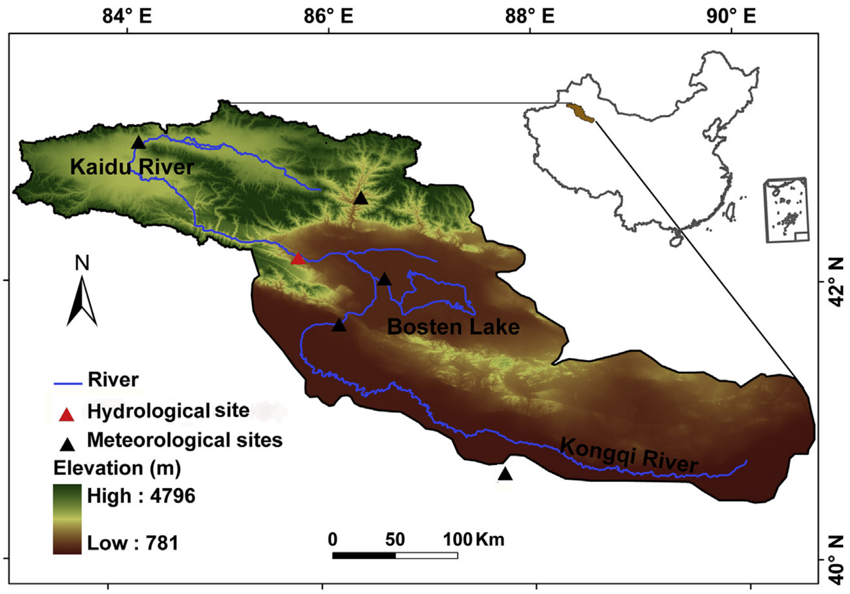

Fig. 1. Kaidu–Kongqi River Basin.

Please cite this article in press as: Wang, Y., et al., Land-use conversion and its attribution in the Kaidu–Kongqi River Basin, China, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.10.010

2.3.2. *Comprehensive index of land use degree*

Land use degree reflects not only the natural attributes of the land use itself, but also the comprehensive effects of human factors and the natural environment (Wang and Bao, 1999). This method divides the land use types into four level indexes according to the different land use patterns (Wang, 2000a) (Table 1). The equation is as follows:

$$\mathrm{Ld} = 100 * \sum_{i}^{n} Ai * Ci \qquad (1)$$

where Ld is the comprehensive index of land use degree; A_i is the ith graded index of land use degree; C_i is the percentage of the area of land use degree classification; n is the graded index of land area utilization degree.

Table 1

Land-use type and land-use grades.

	Level of unused land	Level of forest, grass, water	Level of agricultural land	Level of urban land settlements
Land-use type	Unused land; difficult to use land	Forest; grass and water	Arable land; garden; artificial turf	Urban; residential and industrial; transportation land
Index	1	2	3	4

2.3.3. *Human activity intensity index*

We used the human activity intensity index (Shi and Ehlers, 1996) to evaluate the impact of human activities on the LUCC in the KKRB. The index is calculated as follows:

$$M = U \times 100/(R \times \Delta t) \qquad (2)$$

where U is the total number of pixels of a natural cover type that have been converted to another land use/cover type; R is the total number of pixels of that natural cover type; and Δt is the time interval between two stages. In this study, we used *year* as the unit for the time interval.

3. Results

3.1. *Land-use conversion*

The land use/cover classification maps shows that the land use in the KKRB has experienced considerable change during the past 20 years (Fig. 2). Most notably, the grasslands in the mountain areas have been dramatically reduced since 1990. A great deal of grasslands have converted to either barren lands or cultivated lands. In the middle part of the Basin where the oases are located, the cultivated land has greatly expanded around Bosten Lake since 1990.

Fig. 3 shows the dynamics of all six land use/cover types in terms of percentage. Except for the water body, all the other natural land covers, including the forest, grassland, and unused land, have been decreasing, and both land uses, including the cultivated land and residential and industrial area, have been increasing. However, the rank of total areas of different land use/cover types since 1990 has remained the same: unused land > grassland > cultivated land > water body > forestland > residential area and industrial area. In terms of area, the changes of grassland, unused land, and cultivated land during the 20 years were most dramatic (Table 2).

Table 2

Total change area of LUCC for different periods (km^2).

Periods	1990–2000	2000–2010	1990–2010
Water body	117.18	−54.45	62.73
Forestland	−980.43	−43.75	−1023.18
Grassland	−932.96	−1283.88	−2216.84
Cultivated land	631.92	904.64	1536.56
Residential and industrial area	45.82	53.27	98.09
Unused land	1119.29	425.01	1543.28

The matrices in Table 3 show the land use/cover changes during the two 10-year periods. The figures on the diagonal of a matrix (bold values) are the amounts of those land use/cover types that did not change (persistence) during that period, whereas the off-diagonals indicate the gains, losses, and trajectories of the conversions. For example, Table 3 reveals that out of the 2900 km^2 of the cultivated land in year 2000, 1877 km^2 were unchanged, while 933 km^2, 42 km^2, 25 km^2, 1 km^2, and 23 km^2 were lost to grassland, forestland, residential and industrial area, water bodies, and unused land, respectively. The total cultivated land losses were 1023 km^2. Out of the 3804 km^2 of cultivated land in year 2010, 1927 km^2 were gained from other types, including the grassland (1204 km^2), forestland (340 km^2), residential and industrial area (42 km^2), water body (18 km^2) and unused land (324 km^2). Similarly, out of the 28,230 km^2 of grassland in year 2000, 23,861 km^2 remained unchanged, while 1204 km^2, 240 km^2,18 km^2,41 km^2, and 23 km^2 changed to the cultivated land, forestland, residential and industrial area, water body, and unused land, respectively. Some of the 26,946 km^2 of grassland in year 2010 were gained from the cultivated land (933 km^2), forestland (277 km^2), residential and industrial area (29 km^2), water body (30 km^2), and unused land (1816 km^2).

Table 3a

Nature of the land cover changes from 1990 to 2000 (km^2).

(a) 1990–2000									
		1990							
		C	G	F	R	W	U	Total	Gain
2000	Cultivated land (C)	**803**	1465	240	33	11	348	2900	2097
	Grassland (G)	1151	**23,784**	1104	14	23	2154	28,230	4446
	Forestland (F)	230	258	**314**	5	2	197	1007	693
	Residential and industrial area (R)	21	25	2	**144**	0	61	253	109
	Water body (W)	2	46	37	0	**941**	83	1109	169
	Unused land (U)	61	3583	290	12	16	**40,243**	44,205	3962
Total		2269	29,162	1987	208	993	43,087	77,704	
Loss		1466	5378	1673	64	52	2844		

Please cite this article in press as: Wang, Y., et al., Land-use conversion and its attribution in the Kaidu–Kongqi River Basin, China, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.10.010

Table 3b
Nature of the land cover changes from 2000 to 2010 (km^2).

(b) 2000–2010

		2000							
		C	G	F	R	W	U	Total	Gain
2010	Cultivated land (C)	**1877**	1204	340	42	18	324	3804	1927
	Grassland (G)	933	**23,861**	277	29	30	1816	26,946	3085
	Forestland (F)	42	240	**263**	7	23	388	964	701
	Residential and industrial area (R)	25	18	4	**160**	0	99	306	146
	Water body (W)	1	41	20	0	**876**	117	1055	179
	Unused land (U)	23	2865	103	15	162	**41,461**	44,630	3169
Total		2900	28,230	1007	253	1109	44,206	77,704	
Loss		1023	4369	743	93	233	2744		

The areas of unused land, grassland, and cultivated land are 44,205.1 km^2, 28,230.1 km^2, and 2900 km^2 in year 2000, respectively, accounting for 56.89%, 36.33%, and 3.75% of the total area, respectively. In 2010, these proportions changed to 57.43%, 34.67%, and 4.91%, respectively. On average, the area of grassland decreased with a rate of 110.8 km^2 per year. In other words, 0.15% of the total region area was transferred from grassland into other types per year. Meanwhile, the area of cultivated land increased with a rate of 76.8 km^2 per year. These numbers reveal the general trend in the regional LUCC. During 1990–2010, the dominant land use/cover types, including the cultivated land, grassland, and unused land, had been experiencing dramatic change, whereas the changes of the forestland, water area, and residential and industrial land are relatively small.

3.2. Driving forces for the LUCC

It appears that both natural factors and human activities, and most likely, their interactions, have been the driving forces for the LUCC in this area. Climatic conditions have a restraining effect on utilization of land, which mainly shown in the distribution and composition of crops, grassland and forest, and farming system and yield.

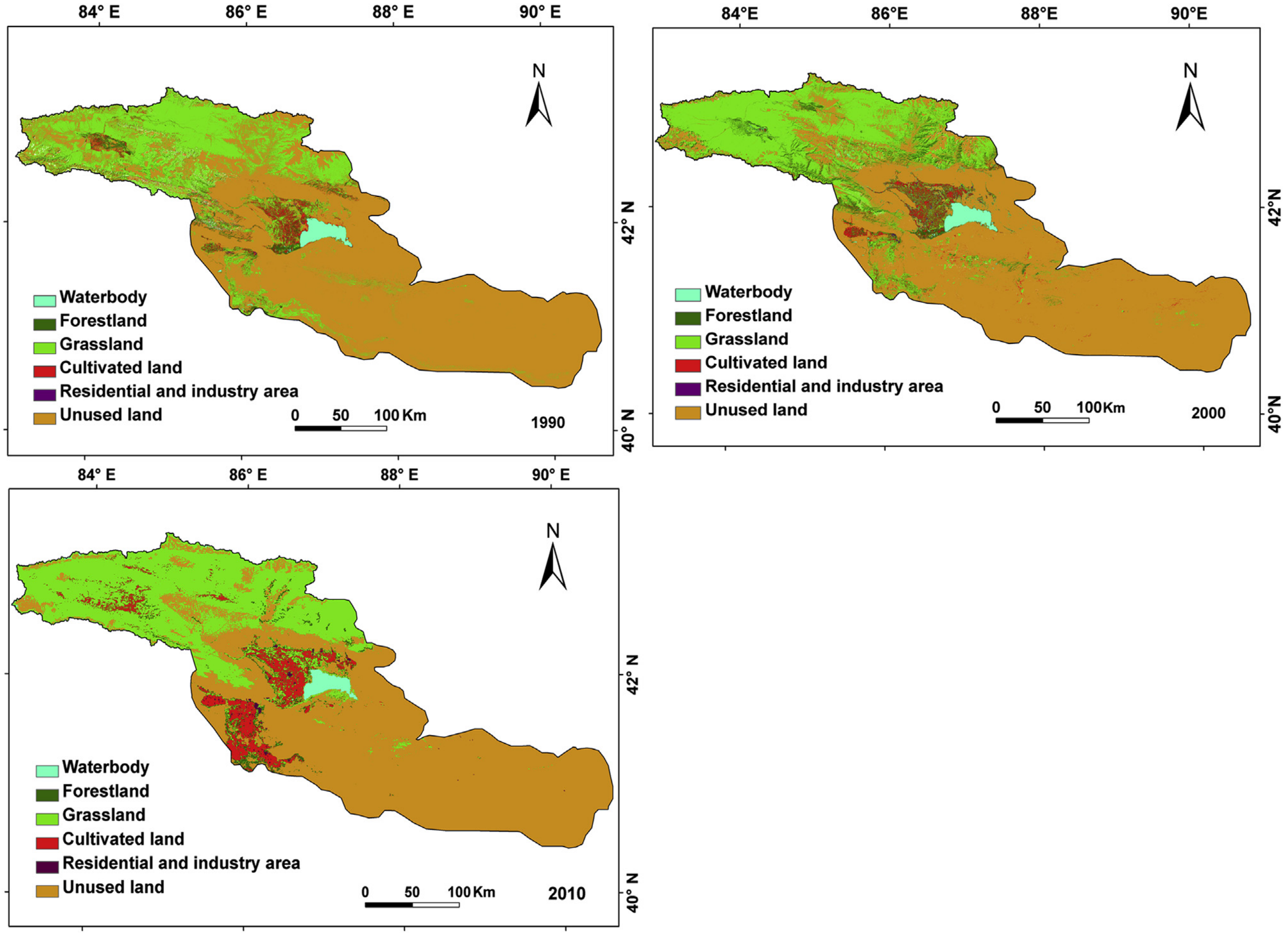

Fig. 2. Land uses in the Kaidu–Kongqi River Basin in 1990, 2000, and 2010.

Please cite this article in press as: Wang, Y., et al., Land-use conversion and its attribution in the Kaidu–Kongqi River Basin, China, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.10.010

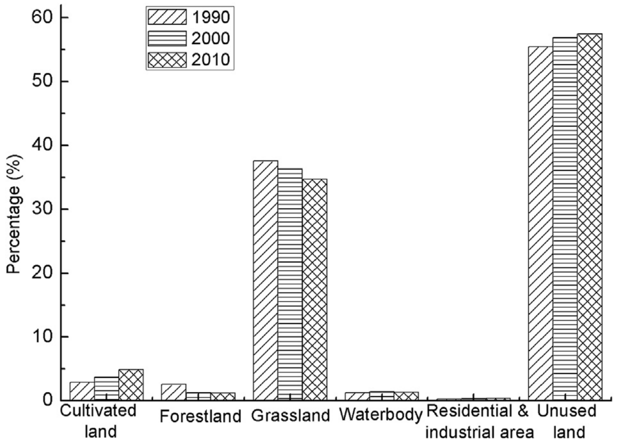

Fig. 3. Percentage of land-cover in the Kaidu–Kongqi River Basin.

3.2.1. *Natural driving factors*

In an arid area such As the KKRB, the land use/cover is largely controlled by the amount and spatial distribution of water. Besides climate factors including temperature and precipitation, topography is another natural factor that has a considerable effect on the land use/cover. The towering mountains stop wet air masses, resulting in relatively abundant precipitation in the mountain areas. The mountain areas are the formation zone of runoff, and the plains are the dissipative zone. Under global climate change, the runoff in the KKRB has been experiencing drastic dynamics, a major factor for the LUCC.

3.2.1.1. Climate change. Fig. 4 shows the temporal variation of climate in the KKRB during 1960–2010. The temperature of the area had an increasing trend, especially in recent two decades (1990–2010). The average annual temperatures during 2000–2010 are higher than those during 1990–1999 by 1.07 C°, 0.56 C°, and 0.41 C° for the mountains, oases, and desert, respectively. During the two decades, the precipitation had a slightly increasing trend during 1960–2010, with an average rate of about 0.5 mm/year for the whole basin. However, the precipitation had decreasing trends in the oases and desert, with rates of −1.2 and −0.5 mm/year, respectively. The average annual precipitation for 2000–2010 is lower than that for 1990–1999 by 19.6 mm, 13.5 mm, and 5.4 mm for the mountains, oases, and desert, respectively. On the one hand, the decreases of precipitation in the oases and desert areas were certainly harmful to both the human system and natural vegetation in those areas, exacerbating the competition between the two systems for water. On the other hand, the increased precipitation and the warming trend in the mountains that had accelerated the melting of snow and glaciers had resulted in increased runoff, which would to an extent balance the decreased precipitation in the downstream areas. However, the extra water from the upstream areas in the form of runoff has given humans more control in the use and allocation of the water. The past 20 years witnessed water management engineering, including dams, gates, canals, and reservoirs, blooming in this area.

In the mountain area, the increasing of precipitation not only supplements the vegetation growth in the mountains, but also produces more runoff, thus providing more water to the irrigation in the oasis region and desert vegetation in the downstream. There is less precipitation and higher evaporation in the plains and desert, with limited surface runoff or infiltration, so that precipitation has less impact on the LUCC in the plains and desert area.

The influence of temperature on LUCC is mainly in the change of meltwater runoff in the mountains. The runoff of the northwest arid area strongly depends on glaciers. Glacier change has a significant impact on water resources in the northwest arid area.

3.2.1.2. Hydrological change. Fig. 5a shows that the runoff of the Kaidu–Kongqi River had an increasing trend during the past five decades. In the most recent two decades, the average annual runoff of the KKRB in 1990, 2000, and 2010 are 29.87 × 10^8 m^3, 49.68 × 10^8 m^3, and 42.25 × 10^8 m^3, respectively, with the amount of the second 10 years is greatly larger than that of the first 10 years. The average annual runoff of 2000–2010 is 40.47 × 10^8 m^3, a 4.5% increase compared with that of 1990–2000.

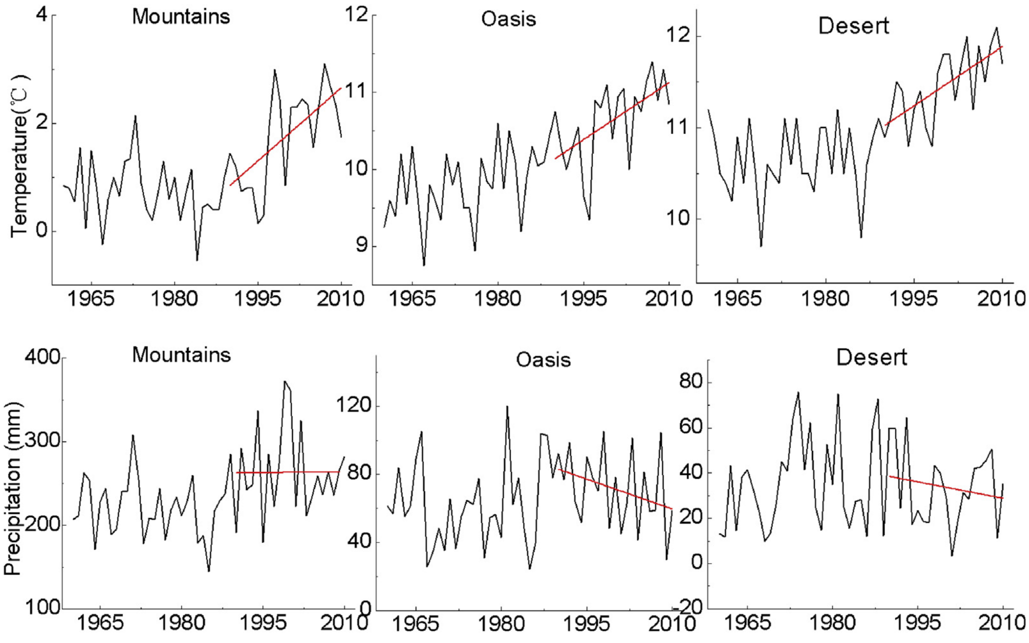

Fig. 4. Trends of temperature and precipitation in the mountains, oases, and desert in the Kaidu–Kongqi River.

Please cite this article in press as: Wang, Y., et al., Land-use conversion and its attribution in the Kaidu–Kongqi River Basin, China, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.10.010

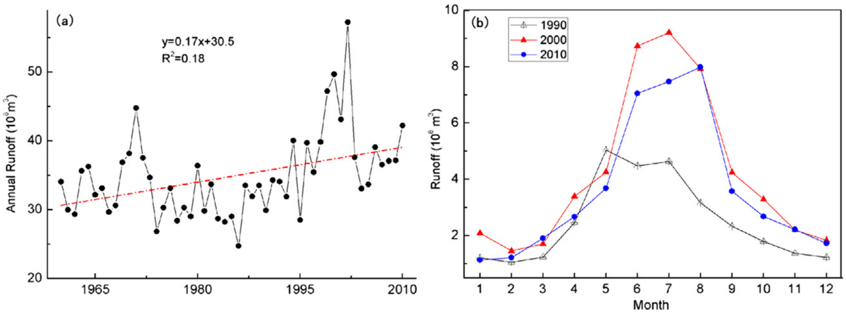

Fig. 5. Change of annual runoff, and runoff within one year in 1990, 2000 and 2010.

Fig. 5b shows a comparison of monthly runoff of 1990, 2000, and 2010. It reveals that the summer runoffs in the second 10 years greatly increased, whereas the runoffs in other seasons largely remained the same or only increased by a small magnitude.

The influences of runoff on LUCC are the following two important aspects: one directly influences the agricultural irrigation water demand, the other directly influences the replenishment of groundwater. Moreover, the years with more runoff replenishment have a relatively high groundwater level compared to years with less runoff replenishment, which is harmful to the desert vegetation downstream.

3.2.2. *Anthropogenic driving factors*

Compared with the natural driving forces, whose effects usually take relatively long times to become noticeable, human activities may have concentrated and immediate impacts on LUCC (Chuluun and Ojima, 2002), particularly the effects and consequences of certain socioeconomic activities and policies (Wang, 2000b). In order to supply the irrigation water of the new reclamation, many new wells were built. There are 3441 wells along the Kaidu and Kongqi River. Plenty of river water was intercepted and the lower reaches of river dried. Salinity was concentrated in the middle reaches of the river region, which led to the deterioration of the secondary salinization, and many farmlands were abandoned.

3.2.2.1. Impact of population growth on LUCC. Population growth can be an essential driving force for LUCC, and meanwhile, the dynamics of population can be a response to the change of environment (Hao et al., 2007, Estes et al., 2012). The population of the KKRB was 121,700 in 1949, 694,400 in 1990, and 1,112,700 in 2010 (Statistical Bureau of Xinjiang Uygur Autonomous Region, 1991–2011). The population growth directly led to expansion of socioeconomic-related land uses. First, the growing population required more land to meet basic needs of living, including food and place of residence; and second, the population's desire for economic development demanded more land for producing commodities. Particularly in this area, a great proportion of cultivated land has been devoted to the profitable cotton production.

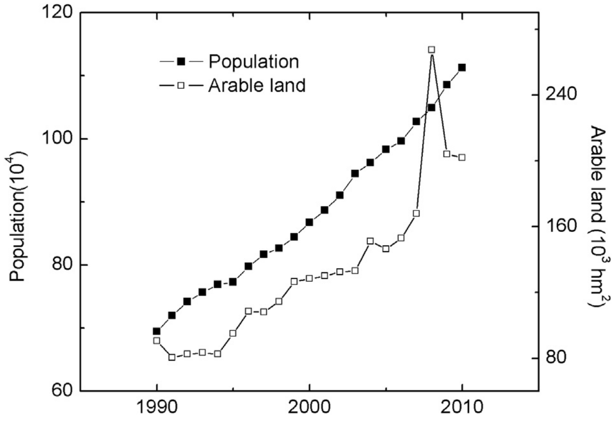

Fig. 6. Changes of population and arable land in the Kaidu–Konqi River Basin during 1990–2010.

Fig. 6 shows the correspondence between the growths of population and arable land in the KKRB during 1990–2010. The correlation coefficient between the two is 0.81. The cultivated land had a slow growth in early 1990s, and then had a jump during 2000–2008. With the continuous growth of population, large areas of wasteland and natural grassland had been reclaimed for cultivation. The area of arable land decreased during 2008–2010, while the population maintained a rising trend. This is the peak period of economic development in Xinjiang, featured by rapid urban sprawl.

The land use degree of the counties and cities in the study area is shown in Table 4, which shows that the land use degree in KKRB belonging to the medium to low level. By calculating the correlation coefficient of land use degree and the population parameters (total population, the total population density, urban population density, rural population density, etc.) in 1990 and 2010, we found that the total population density has the most closely relationship with the land use degree. Therefore, we choose the total population density as the parameters to establish the population differentiation model.

Table 4
Land-use degree of Kaidu–Kongqi River Basin.

Counties and cities	1990	2000	2010
Bohu	159	161.7	163.4
Hejing	179.2	179	180.2
Heshuo	142	135.3	131.1
Yanqi	216.1	215.4	215.7
Yuli	125.4	123.1	124.6
Korla	170.7	170.2	169.8

The relationship between the degree of land use utilization (Ld) and the total population density (dp) are shown in Fig. 7. The quadratic curve fitting formulation is:

$$\mathrm{Ld} = 146.28 + 0.4032\mathrm{dp} + 0.0229\mathrm{dp}^2 \quad \mathrm{Ld} \in \left[100, 400\right] \quad R = 0.78$$

$$\mathrm{Ld} = 150.55 + 0.8250\mathrm{dp} + 0.0036\mathrm{dp}^2 \quad \mathrm{Ld} \in \left[100, 400\right] \quad R = 0.86$$

Fig. 7(a) and 7(b) shows the scatter plot and regression curves, which represent the correlation between the land use degree and

Please cite this article in press as: Wang, Y., et al., Land-use conversion and its attribution in the Kaidu–Kongqi River Basin, China, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.10.010

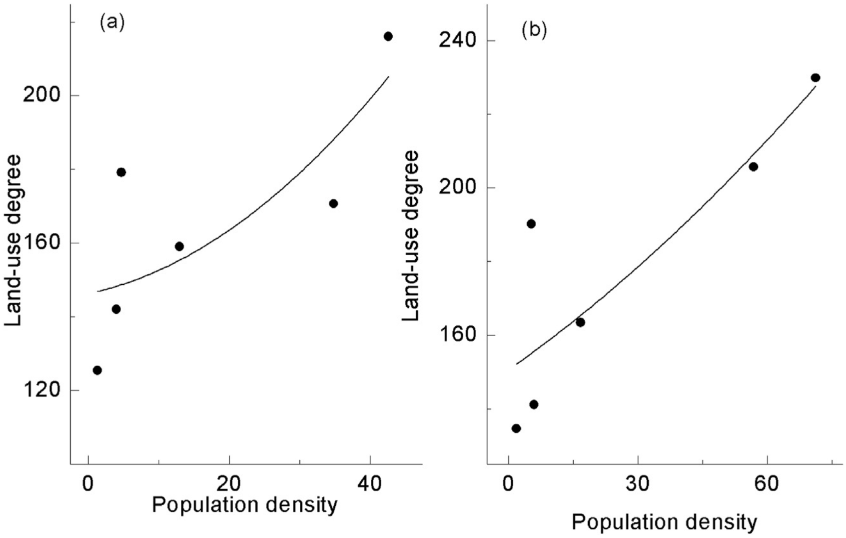

Fig. 7. Relation between land-use degree and population density of Kaidu–Konqi River Basin in 1990 and 2010.

population density. The coefficients $R = 0.78$ in 1990, and $R = 0.86$ in 2010 which passed the 0.01 significant test. The total population density has the closest relationship with the land use degree. Since the land use patterns in the study area is mainly based on agriculture, forestry, animal husbandry, the land use change mainly reflects their mutual changes. Therefore, the population has a very important impact.

To quantitatively characterize the impact of human activities on the LUCC, we calculated the human activity intensity index (Eq. (2)) for the periods of 1990–2000 and 2000–2010, based on the land use/cover classifications of 1990, 2000, and 2010. The index values for the two periods are 0.75 and 0.88, respectively, indicating that the degree of human activities in this area had been increasing during the two decades.

3.2.2.2. Effect of the ecological water conveyance project on land cover change. The influence of human activities on LUCC is the development of former wasteland. Oases mainly support the agricultural economy. Because of the limitation of the condition and the law, the distribution of the vegetation/crops shows significant variation. So, the LUCC changes with human activities, particularly in the oasis region.

In groundwater-dependent ecosystems, the dynamics of soil moisture, relative to the water table fluctuations, control the overall ecosystem dynamics. The ecological water transfer and rehabilitation project in the arid inland area of northwest China is an important measure in restoring a deteriorated ecosystem. For example, water conveyances of the lower reaches of Tarim River have a positive effect on the water level raise. The natural vegetation's form, distribution and growth trend have the close relationship with underground moisture. In the transversal direction, the ecological water conveyance effect to the vegetation is decreasing, the groundwater level is decreasing with the distance to the canal increasing, and the vegetation response is always linear along the canal. However, people living in and adjacent to ecological restoration areas are highly dependent on the water resources for food, grassland for livestock, and other products. Despite its potential for improving the regional and local ecological environments, the sustainability of the project is affected by several socioeconomic factors, including the readjustment of economic restructure and the economic compensation and employment of local farmers and herdsmen.

4. Discussion and conclusion

Based on the land use/cover classification data derived from the Landsat TM imageries in 1990, 2000, and 2010, along with the governmental socioeconomic statistics and field observation data, we investigated the land use/cover change (LUCC) in the Kaidu–Kongqi River Basin (KKRB) in the arid region of northwest China (ARNC) during the two decades from 1990 to 2010. Our findings include: (1) The LUCC in the KKRB during the two decades was considerable, especially on the grassland and cultivated land. The natural grassland in the area had been decreasing by a rate of 118.1 km^2 per year, whereas the cultivated land had been increasing by a rate of 79.2 km^2 per year. The rapid expansion of cultivated land was mainly due to reclamations of unused land and natural grassland. (2) The LUCC has been a result of both natural environmental changes and increasing human activities. The changing runoff due to climate change has played a fundamental role in the LUCC. The human activity intensity index value rose from 0.75 for 1990–2000 to 0.88 for 2000–2010. (3) Based on the relationship between the population and land use change, this paper established the population differentiation model, and found that population directly affect the land use change. The land use degree is increasing as the population density increases, which illustrates that the population directly affects the land use/cover change.

A limitation of this study is that our land use/cover data have a 10-year interval, which may not fully reflect the spatial and temporal patterns of LUCC in the area. Increasing the temporal resolution of the study is an important item on the agenda of future research.

Acknowledgements

The research is supported by the National Basic Research Program of China (973 Program: 2010CB951003).

References

Briggs, J.M., Knapp, A.K., Blair, J.M., Heisler, J.L., Hoch, G.A., Lett, M.S., Mccarron, J.K., 2005. An ecosystem in transition: causes and consequences of the conversion of mesic grassland to shrubland. BioScience 55, 243–254.

Brovkin, V., Sitch, S., Bloh, V.W., Claussen, M., Bauer, E., Cramer, W., 2004. Role of land cover changes for atmospheric CO2 increase and climate change during the last 150 years. Global Change Biology 10, 1253–1266.

Chen, Z.S., Chen, Y.N., Li, B.F., 2012. Quantifying the effects of climate variability and human activities on runoff for Kaidu River Basin in arid region of northwest China. Theoretical and Applied Climatology 111 (3–4), 537–545.

Please cite this article in press as: Wang, Y., et al., Land-use conversion and its attribution in the Kaidu–Kongqi River Basin, China, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.10.010

Chen, Y.N., 2013. Sustainable Utilization of Water Resources in the Bosten Lake Basin. Science Press, Beijing.

Chuluun, T., Ojima, D., 2002. Land use change and carbon cucle in arid and semi-arid lands of east and central Asia. Science in China 45 (Suppl.), 48–56.

Estes, A.B., Kuemmerle, T., Kushnir, H., Radeloff, V.C., Shugart, H.H., 2012. Land-cover change and human population trends in the greater Serengeti ecosystem from 1984-2003. Biological Conservation 147 (1), 255–263.

Fu, C.B., 2003. Potential impacts of human-induced land cover change on East Asia monsoon. Global and Planetary Change 37 (3–4), 219–229.

Feddema, J.J., Oleson, K.W., Bonanetal, G.B., 2005. Atmospheric science: the importance of land-cover change in simulating future climates. Science 310, 1674–1678.

Fang, S.F., Yan, J.W., Che, M.L., 2013. Climate change and the ecological responses in Xinjiang, China: model simulations and data analyses. Quaternary International 311, 108–116.

Falcucci, A., Maiorano, L., Boitani, L., 2007. Changes in land-use/land-cover patterns in Italy and their implications for biodiversity conservation. Landscape Ecology 22, 617–631.

Gan, T.Y., 1998. Hydroclimatic trends and possible climatic warming in the Canadian Prairies. Water Resources Research 34 (11), 3009–3015.

Hietel, E., Waldhardt, R., Otte, A., 2005. Linking socio-economic factors, environment and land cover in the German Highlands, 1945-1999. Journal of Environment Management 75, 133–143.

Huang, X.Z., Chen, F.H., Fan, Y.X., Yang, M.H., 2009. Dry late-glacial and early holocene climate in arid central Asia indicated by lithological and palynological evidence from Bosten Lake, China. Quaternary International 194, 19–27.

Hao, X.M., Li, W.H., Chen, Y.N., Zhao, R.F., 2007. Analysis of socio-economic driving forces on land use and land cover change in Tarim River Basin. Journal of Desert Research 27 (3), 405–411.

Lioubimtseva, E., Cole, R., Adams, J.M., Kapustin, G., 2005. Impacts of climate and land-cover changes in arid lands of Central Asia. Journal of Arid Environments 62 (2), 285–308.

Li, B.F., Chen, Y.N., Shi, X., 2012. Why does the temperature rise faster in the arid region of northwest China? Journal of Geophysical Research 117, D16115.

Liu, J.Y., 1992. Land Use in Tibet. Science Press, Beijing, pp. 78–96.

Luo, G.P., Chen, X., Zhou, K.F., 2002. Temporal variability and the stability of oasis in SangongRiver. Science in China Series D 32 (6), 521–528.

Luo, G.P., Zhou, C.H., Chen, X., 2003. Process of land use/land cover change in the oasis of arid region. Acta Geographica Sinica 58 (1), 63–72.

Pyke, C.R., Andelman, S.J., 2007. Land use and land cover tools for climate adaptation. Climatic Change 80, 239–251.

Sulieman, H.M., Elagib, N.A., 2012. Implications of climate, land-use and land-cover changes for pastoralism in eastern Sudan. Journal of Arid Environments 85, 132–141.

Shi, W.Z., Ehlers, M., 1996. Determining uncertainties and their propagation in dynamic change detection based on classified remote sensed images. International Journal of Remote Sensing 171 (14), 1100–1117.

Statistical Bureau of Xinjiang Uygur Autonomous Region, 1991–2011. Xinjiang Statistical Yearbook. China Statistics Press, Beijing.

Wei, W.S., 2000. Respondence and feedback of modern sand deserts to climate change - a case study in Gurbantunggut Desert. Chinese Science Bulletin 45 (12), 1137–1142.

Wang, T., 2000a. Land use and sandy desertification in the North China. Journal of Desert Research 20 (2), 103–107.

Wang, X.Z., Zheng, Y.H., Li, S., 2006. Analysis of land use and landscape pattern change in west of HainanIsland. Journal of Desert Research 26 (3), 409–414.

Wang, X.L., Bao, Y.H., 1999. Study on the methods of land use dynamic change research. Progress in Geography 18 (1), 81–87.

Wang, X.L., 2000b. Analysis on demographic factors and land use/land cover change. Resources Science 22 (3), 39–42.

Xu, C.C., Chen, Y.N., Chen, Y.P., Feng, Z.D., Ding, H., 2013. Responses of surface runoff to climate change and human activities in the arid region of Central Asia: a case study in the Tarim River Basin, China. Environmental Management 51 (4), 926–938.

Please cite this article in press as: Wang, Y., et al., Land-use conversion and its attribution in the Kaidu–Kongqi River Basin, China, Quaternary International (2014), http://dx.doi.org/10.1016/j.quaint.2014.10.010