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ORIGINAL ARTICLE

Re-evaluating the impacts of human activity and environmental change on desertification in the Minqin Oasis, China

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Abstract The Minqin Oasis and its adjacent regions in northern China experienced significant desertification beginning 2,000 years ago and continuing to the present, and numerous studies have claimed that human activities, especially the flourishing of agriculture, have played a major role in environmental change in this region. Our analysis suggests that the observed desertification was mainly controlled by changes in the water component of the ecosystem and the arid climate. The impacts of cultivation on desertification from 2,000 years ago to the mid-1900s appear to have been relatively minor compared to the impacts of the area's arid climate and its native geomorphological processes. Although human activity has increased from the late-1940s to the present, and the areas of the oasis reclaimed for agriculture have reached a maximum, desertification over the past 50 years appears to be a continuing process that began thousands of years ago, and is mainly controlled by decreasing water levels caused by the arid climate, local geomorphological processes and overuse of water in the upstream. Although both human activities and climate variation are important drivers of the desertification process, and it is not possible to completely separate the human influence from the climate impact, key factors on controlling desertification should be investigated before we place the blame solely on the flourishing of agriculture in this region.

Keywords Human activity · Water utilization · Desertification · Arid China

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Introduction

The Minqin Oasis is located in the western part of North China, northeast of the Hexi Corridor, and is a hyperarid region with annual precipitation of about 113 mm (1954–2002), versus evaporation of 2,640 mm (1954–2001). The region is surrounded by the Badain Jaran and Tengger deserts along its western, northern, and eastern margins, and the formation and evolution of the oasis have been controlled by the evolution of the Shiyanghe River and its tributaries, which originate on the eastern slopes of the Qilian Mountains (Fig. 1). In addition, the oasis and its adjacent areas represent a typical region whose ecological systems are vulnerable due to low precipitation, high evaporation, and sand transport. As a result, the region has experienced significant environmental changes over the past 2,000 years (Feng 1963; Li 1998), and at present is considered to be a representative region of very severe desertification by the Chinese government and UNEP (1992) due to the high density of human activity in this region. Echoing the assertions of environmental protection organizations, and in conformity with the government's goal of controlling desertification, numerous studies have been carried out on the environmental changes in this region in terms of the history of water use (e.g., Yang et al. 2002), human activities (Xie et al. 2004a, b; Li 1999; Wang et al. 2003), and climate change throughout the Holocene (Chen et al. 2003). As a result of some of these studies and in response to pressure from environmental organizations, the Chinese government will invest 4.3 billion RMB (approximately US$540 million) in coming 10 years to control desertification in this region.

However, although researchers have suggested many approaches to rehabilitate the region environment, and there is no dispute that both climate change and human activities have acted together to change the region environment, there have been few integrated analyses of the key causes of desertification in this region. For instance, Li (2001) suggested that the area of oases in this region have not decreased in recent decades, and may in fact be larger than that during the Western Han Dynasty (206 B.C. to 24 A.D.). Oasis degradation in some regions may be accompanied by the development of oases in adjacent regions due to river realignments, and in this case, the oasis degradation in these surrounding regions will not be due mainly to unsustainable human activities. In addition, Hinsch (1988) suggested that the farming culture in the North China was significantly vulnerable to climate change, and Hsu (1998) indicated that the relatively cold climate during the past 3,000 years may have caused famines and national migrations in China and around the world. In some desert regions, humans may thus have had relatively low impacts on the evolution of the regional environment in comparison with long-term climatic and geomorphological changes (e.g., Wang 2002; Han 2003).

Of course, numerous studies have also supported the contention that human activity, such as reclamation, which refers to drainage of wetlands to expose fine-textured soils with good moisture availability that are suitable for agriculture, is responsible for desertification in this region. For instance, Wang et al. (2003) and Xie et al. (2004b) suggested that over-use of the region's water resources and a rapid increase in the region's population were the principal causes of rapid desertification in the past 100–300 years; Yang et al. (2002) also stated that over the past 50 years, the degradation of oases in this region has been due to the expansion of traditional agriculture, which to a large extent is supported by heavy use of water resources. Xie et al. (2004a) also suggested that over-reclamation of land for agriculture from the late 1950s to the early 2000s accelerated desertification. These studies tend to suggest that climate change and geomorphological processes have had very low impacts on environmental change in this region, in contrast with abrupt climate change, which is expected to become a crucial factor in determining the ecological health of China and other regions around the world (Hinsch 1988; Weiss et al. 1993, Wang et al. 1996; Wang 1996; Cullen et al. 2000; Weiss and Bradley 2001; Zhang 2003; Haug et al. 2003).

In the present paper, based on re-interpretation and critical review of previously published data and combing with our field investigations, we have performed a detailed analysis of water and land utilization, the evolution of drainage systems, precipitation and temperature records, and historical records on human activities in the region. On this basis, we discuss the roles of climate change, geomorphological processes, and human activities on the evolution of desertification in the Minqin Oasis and its adjacent regions, and attempt to clarify the key causes of desertification in this part of arid China. In addition,

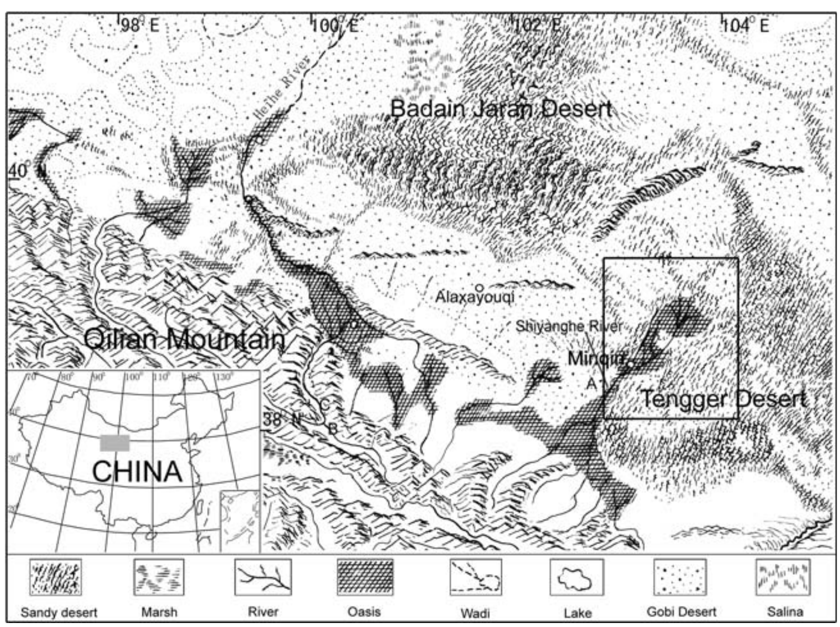


Fig. 1 Map of the Minqin Oasis and its adjacent regions. The scope of the Minqin Oasis is identified by the *rectangle* at the right side of the map

because there are complete records of climate and proxies of human activities such as the area of farmland, population size, and areas of reclaimed oasis from 1949 to the present, we therefore discuss the roles of these factors in desertification before and after 1949.

Oasis evolution and desertification processes in Minqin Region

Oasis evolution and controlling factors from the mid-Holocene to 1949 A.D

At least during the Tertiary Period, the region of the Minqin Oasis developed as a basin, and throughout the Quaternary Period, the region has subsided slowly and sediments from adjacent areas have been deposited in the basin by wind and water. Although it is currently difficult to obtain high-resolution data on the evolution of the oasis, there appear to have been at least ten cycles of arid events throughout the Holocene Period, and this region experienced low lake levels during the mid-Holocene at around 5000–7000 cal year BP. From 2500 cal year BP to the present the climate in this region changed from wet to dry (Chen et al. 2003), which is consistent with the pattern of lake evolution over the past 2,500 years in this region. After 5000 cal year BP, this region developed an extensive lake due to the relatively high precipitation and abundant inflow of water from rivers that developed in the Qilian Mountains during previous periods. In addition, although the water levels of lakes increased during certain parts of this period, from 475 B.C. to the present, there has been a continuous trend of a decreasing area of lakes in this region because water loss has been far larger than recharge in this basin. Accordingly, the areas of oases, grasslands, swamplands, sandy deserts, and alkaline lands increased in phase with the decline in lake levels (Fig. 2). Although some human activity occurred in the region during the early Holocene (Feng 1963), extensive oasis reclamation was not carried out until the Western Han Dynasty (206 B.C. to 24 A.D.; Li 1998), and evolution of the oasis in this region during this period was significantly controlled by the arid climate and geomorphological processes.

After 206 B.C., numerous records of human activity in this region have been preserved in ancient Chinese historical records. Although more and more land was reclaimed between this period and the early 1900s (Fig. 3), the reclaimed areas were mainly limited by the presence of water resources; over the past 3,000 years, humans used water resources was still in a relatively low levels, and farmland in many locations was abandoned due to realignments of rivers and decreases in groundwater levels and the area of lakes in this region (Li 1998, 1999). For instance, farmlands reclaimed during the Western Han Dynasty (206 B.C. to 24 A.D.) were abandoned by the end of the Tang Dynasty (618 to 907 A.D.) due to river diversion and decreases in the available water resources. However, land in the same locations was reclaimed again after the mid-1900s due to improved water resources (Li 2001). In addition, the oases in the middle reaches of the Shiyanghe River reclaimed between 220 and 316 A.D. were abandoned due to deterioration in the moisture conditions. The oases in the end of the Shiyanghe River, were extensively reclaimed after 1644 A.D. due to declining lake levels in the region, which provided large areas in which the water table remained near the surface, and abundant fine materials and nutrients for farming. In general, the degradation of oases during these periods was not due to over-farming or other human activities, but rather resulted from changes in the moisture conditions.

A previous study (Hou 1973) proposed that population size is a major factor that controls desertification in arid and semiarid China. In the Minqin Oasis and its adjacent regions, the presence of large populations has indicated periods of flourishing agriculture, whereas small populations have indicated the development of grazing; this change occurs because agriculture can provide more food than grazing and can thus sustain larger populations (Wang 1996; Zhang 2003). Over the past 2,000 years, farming and grazing cultures have alternated in the Minqin Oasis and its adjacent regions. Before 1910 A.D., the highest population in the Minqin Oasis and its adjacent regions was 184 542 (Liang 1993) or between 220,000 and 250,000 (Wang et al. 2003), and this relatively high population mainly occurred from around 500 to 900 A.D. and after the late 1800s. During the periods between the Western Han and Eastern Jin dynasties (206 B.C. to 420 A.D.) and the Sui and Tang dynasties (581 to 907 A.D.), and after 1368, extensive reclamation of oases occurred in response to high population pressure, and efficient irrigation systems also appeared during these periods (Li 1998; Wang 2004). However, grazing developed and rapid desertification occurred were accompanied by significantly decreased population size during periods with cold climate (Fig. 4; Hinsch 1988; Hsu 1998) and frequent warfare (Zhang et al. 2005).

In addition to changes in population size and the evolution of the water component of the ecosystem, previous studies have suggested that precipitation (e.g., Chang et al. 2004, 2005) and the amount of water flowing into this region also played important roles in the evolution of the Minqin Oasis and its adjacent regions. Although no direct measurements exist for variations in precipitation over the past 2,000 years, dendrochronology studies (Kang et al. 2003) that used tree rings in a region adjacent to the Minqin Oasis as a proxy for these variations revealed different

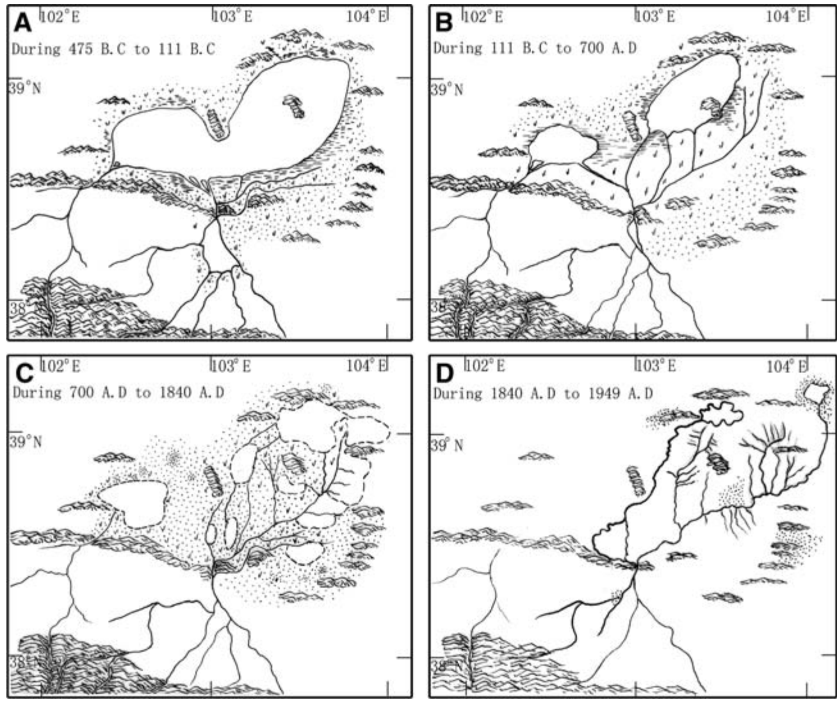


Fig. 2 Evolution of the main bodies of water in the Minqin Oasis basin from 475 B.C. to 1911 A.D. Modified after Feng (1963)

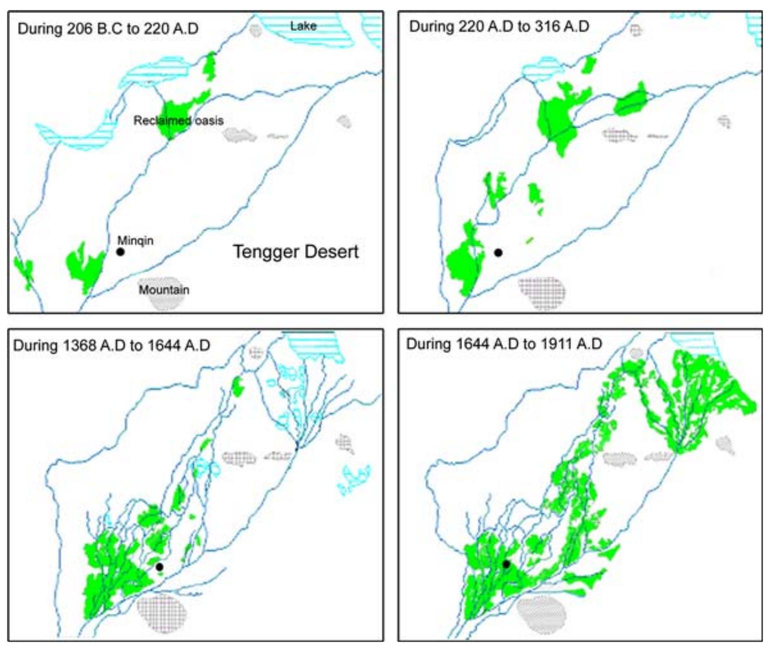


Fig. 3 Areas and locations of reclaimed oases from 206 B.C. to 1911 A.D. in the Minqin Oasis. Modified after Xie et al. (2004a)

cycles of precipitation. The longest periods of rain seasons in this region were at 1240 to 1270 A.D. and 1860 to 1890 A.D. (Fig. 5). From 1240 to 1270 A.D. the agriculture in this region was replaced by grazing. It seems that the precipitation trends during this period had no significant impact on environmental changes and oasis development because the variation in precipitation between 900 A.D. and the early 2000s was <10% (<15 mm in the Minqin Oasis and its adjacent regions), and this suggests relatively low impacts on the vegetation cover and on oasis development. Compared to rainfall events, water inflows have a stronger potential impact on evolution of the oasis. The amount of runoff from the Qilian Mountains, reconstructed from the tree ring data, show that over the past 1,400 years, there have been periods of relatively high amounts of runoff around 800, 1000, 1300, and 1700 A.D. (Fig. 6). During these periods, there was a relatively high population in the Minqin Oasis and its adjacent regions, accompanied by increases in the area of reclaimed oases and predominance of farming over grazing (Fig. 4). During

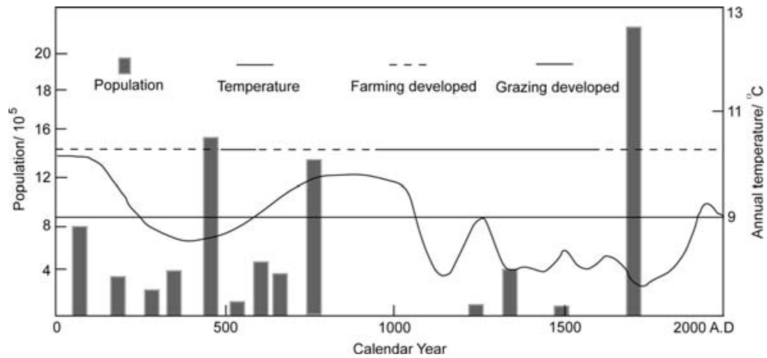


Fig. 4 Population levels and stages during which farming and grazing predominated during different periods in the Minqin Oasis and its adjacent regions, and relationships with temperature trends in China over the past 2,000 years. Modified and compiled after Zhu (1973), Wang et al. (1996, 2003), Zhang (2003)

the 1700s, extensive land reclamation occurred in this region, which was also the period with the highest moisture level since 5000 cal yr B.P. (Li 1996; Chen et al. 2003).

Oasis development and environmental evolution after 1949

After 1949, the available water resource was the major control on development of the Minqin Oasis and adjacent regions. The area of reclaimed oasis increased, while water inflow to the Minqin Oasis decreased continuously from the 1950s to the early 2000s due to significant increases in water consumption in the headwater areas that supply the oasis. For instance, the water inflow from six major tributary rivers to the Minqin Oasis in 1957 was 4.64×10^8 m^3, which represents 34.86% of the total runoff into the whole basin area; inflow had decreased to 0.98×10^8 m^3 in 2000, which amounts to only 7.52% of this total (Table 1; Sun 2004). In addition, groundwater levels decreased; in some regions, the water table lay at a depth of about 2 m in the 1950s, but had increased to a depth of more than 12 m by the late 1990s (Chen 1995; E et al. 1997; Tables 2, 3). This change resulted in extensive sandy desertification due to a decrease in vegetation cover throughout this region. Furthermore, some lakes existed in this region during the early 1940s, but by the early 2000s, all these lakes had disappeared, leaving extensive wadis and lands too alkaline for cultivation.

Before 1949, the largest population in the region was between 180,000 and 250,000, but from 1949 to 2000 the population increased to 300,000. Previous studies (e.g., Yang et al. 2002) suggested that this high population size was the principal contributor to degradation of the land during the past 50–300 years in the Minqin Oasis and its adjacent regions. Accompanying this increase in population, the area of reclaimed oases expanded by 258.2 km^2 from 1953 to 1973, by 145.6 km^2 from 1973 to 1987, by 315.7 km^2 from 1987 to 1994, by 249.4 km^2 from 1994 to 1998, and by 88.2 km^2 from 1998 to 2001. After 2001 to the present lands with fine moisture conditions were fully reclaimed. Although the area of reclaimed oases increased greatly over the past 50 years, especially during the past 20 years (Table 4), our field investigations and interviews with local inhabitants provide little evidence that the flourishing of agriculture during this period was responsible for the simultaneous desertification that occurred in this region. Because, over the past 2,000 years irrigation for farmlands in this region were mainly depended on water in rivers, while these newly reclaimed oases after 1949 were mainly located at the margins of sandy and gobi deserts, which represent regions with low availability of water. Thus, these newly reclaimed oases were quickly abandoned and desertification rapidly occurred due to significant

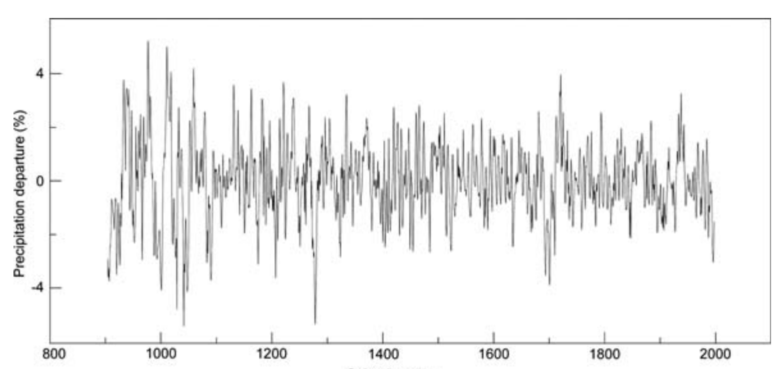


Fig. 5 Precipitation trends in the regions adjacent to the Minqin Oasis from 910 A.D. to the present. The source of the tree ring data is labeled B in Fig. 1. Modified after Kang et al. (2003)

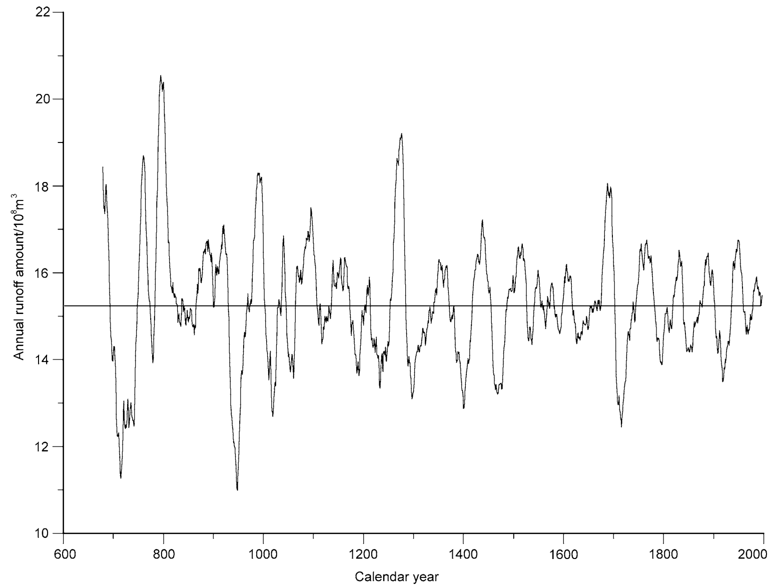


Fig. 6 Annual amount of runoff (20-year running mean) in the Qilian Mountains adjacent to the Minqin Oasis from 600 A.D. to the present. The source of the tree ring data is labeled C in Fig. 1. The data was provided by Prof. Kang of CAREERI, and the figure is modified from Kang et al. (2002)

decrease in water inflow and groundwater levels and changes in stream and river locations. During the early 1900s, land suitable for reclamation as a result of appropriate moisture conditions totaled nearly 1,200 km^2 in this region (Qiao and Xie 2004; Xie et al. 2004a), but the total area declined after 1949 due to significant decreases in water inflow.

Discussions

The history of oasis reclamation, agriculture, and grazing in the Minqin Oasis, which to a large extent has been controlled by water resource limitations, exceeds 2,000 years. In this region, the major water resources include surface water in lakes, groundwater, and water inflow from rivers. Precipitation, which is a major water resource in other regions, may have some impact on the vegetation cover, but has a low overall impact on environmental change because of its extremely low value (around 110 mm per year) in this region. Figure 7 presents an over view of water balance in the Minqin Oasis and adjacent regions, including the sources of water (inputs) and sources of water loss (outputs). The flourishing of agriculture in this region depended on the development of irrigation canals and ditches throughout the region, which began during the Western Han, Tang, and Qing dynasties of China (Li 1998, 1999). However, the distributions of these artificial water resources were also controlled by water inflow into this region and by groundwater levels. In areas with high groundwater levels or adjacent rivers, the land is used extensively for farming because these resources provide an adequate water supply; in contrast, the farmland will be abandoned when the groundwater level decreases or river realignments occur. Also, the results in Fig. 3 show that over the past 2,000 years, areas of the oasis have been repeatedly reclaimed for agriculture then abandoned, which suggests that the desertification caused by humans was repaired by the ecosystem and whose magnitude was less than that of the changes imposed by the environmental fluctuations. In addition, historians reported floods and waterlogging before 1644 (Li 1996), and after

Table 1 Total water inflow from the six major rivers and the inflow into the Minqin Oasis. Data from Sun (2004)

Year	Water inflow to the Minqin Oasis (10^8 m^3)	Inflow to the Minqin Oasis as a proportion of the total inflow (%)
1957	4.64	34.86
1969	3.94	30.19
1976	2.68	19.09
1980	2.21	17.00
1990	1.70	12.07
1991–1997 averaged	1.59	14.34
2000	0.98	7.52

Table 2 Variations in the depth of the water table from the 1960s to the late 1990s in the Shajinzi area. The location of Shajinzi is labeled A in Fig. 1. Data from E et al. (1997) and E (2005)

Period	Groundwater depth (m)	Rate of depth increase (m/year)
1961–1967	2.24–2.93	0.12
1967–1978	2.93–5.20	0.21
1978–1988	5.20–9.00	0.38
1988–1994	9.00–12.99	0.67
1994–2000	>20.00	>1.00

Table 3 Variations in the depth of the water table from the 1960s to the late 1990s in the Minqin Oasis. The location of Shajinzi is labeled A in Fig. 1. Data from E et al. (1997) and E (2005)

Period	Groundwater depth (m) within the Oasis	Groundwater depth (m) in southern margins of the Oasis	Groundwater depth (m) in northern margins of the Oasis
In the early 1960s	1.7–3.5, Max > 3.5	1.0–1.7	1.0–1.7
In the mid-1960s	2.0–3.5, Max 3.9–4.0	1.7–3.0	
In the early 1970s	2.5–5.5, Max > 5.5	1.2–1.7	>2.0
In the mid-1970s	Max > 6.6	1.2–1.9	3.0–3.3
In the early 1980s	Max > 8.0	2.0–2.5	<4.3
In the mid-1980s	Max > 12.7	2.5–3.0	5.0–7.0
In the early 1990s	Max > 15.0	<10.0	
In the mid-1990s	Max > 18.0	12.0–13.0	
In the early 2000s	Max ~20.0	15.0–17.0	

Table 4 Areas of reclaimed oases and rates of increase in reclamation as a function of the 1959 value during different periods in the Minqin Oasis. Data were provided by Dr. Yaowen Xie of Lanzhou University

Year	1959	1973	1987	1994	1998	2001
Area (km^2)	929.92	1061.19	991.67	1124.40	1231.70	1099.34
Rate of increase (%)	–	14.12	6.64	20.91	32.45	18.22

1644 there were disputes over the allocation of water resources between upstream and downstream regions of the Shiyanghe River (Wang 2004), indicating that the water resources were still abundant 300 years ago. At the time, extensive lakes also existed due to high water inflow into this region (Fig. 2). From 1949 to the present, significant declines in water inflows (Table 1) resulted in drying of lakes, decreases in groundwater levels (Tables 2, 3), and the expansion of areas of saline and alkaline lands and mobile sands. From the 1970s to the present, most saline and alkaline and sandy lands and wadis were reclaimed in this region, and irrigation of these lands depended mainly on groundwater because of the absence of surface water. However, the residence time of groundwater in this region is longer than 1,000 years (Shi et al. 1999), and the groundwater levels will continue to decrease if there is no additional input of water.

From 206 B.C. to 24 A.D, 220 to 316 A.D., 1368 to 1644 A.D., and 1644 to 1911 A.D., the total areas of unreclaimed oases, lakes, swamplands, and grasslands during these periods were 4,805, 4,572, 3,507, and 2,888 km^2, respectively; in comparison, the corresponding areas of reclaimed oases were 148, 278, 266, and 758 km^2 (Fig. 8). The results indicate that the lands with degradation occurrence exceeded 1,900 km^2, whereas the increase in the area of reclaimed oases was only 610 km^2 from 206 B.C. to 1911 A.D., which suggests that the significance of water resource limitations was far higher than the impact of

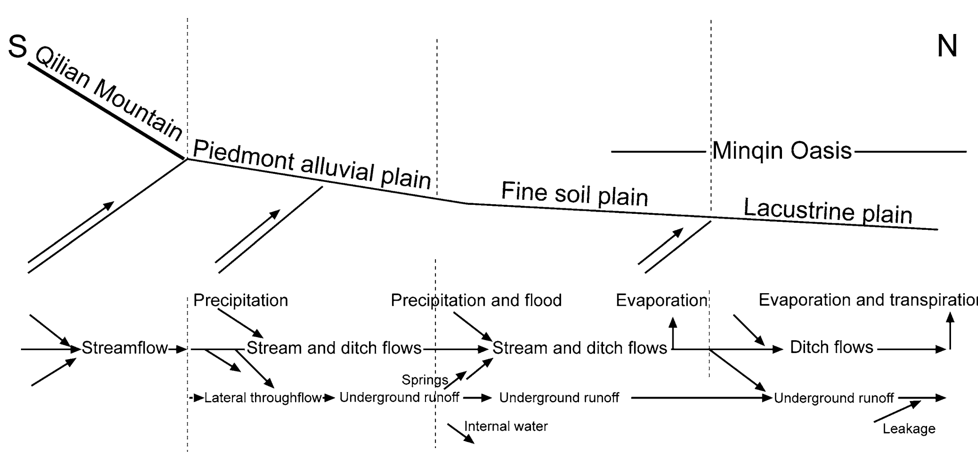


Fig. 7 An over view of water balance in the Minqin Oasis and adjacent regions over the past 2,000 years. Modified after Xu and Zou (1989)

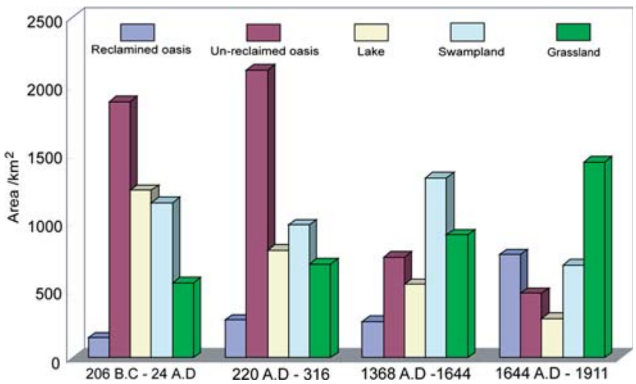


Fig. 8 Total areas of reclaimed oases, unreclaimed oases, lakes, swamplands, and grasslands from 206 B.C. to 1911 A.D. Data are from Xie (2003)

oasis reclamation, even if we consider oasis reclamation to be a form of desertification. In addition, in the more recent period from 1949 to the present, extensive reclamation occurred between the late 1980s and the late 1990s, and most cropland that was reclaimed during this period became covered by mobile sands by the early 2000s. Our field investigations indicate that the rapid occurrence of desertification in these regions was due to a combination of vulnerable vegetation and low moisture availability, and that the degradation was most often located at the margins of sandy and gobi deserts despite that these regions are reclaimed or not (Fig. 9). In addition, the desertification will not occur in these farmlands during it is used for farming, but the desertification will occur if it be abandoned due to absences of water resources. In these regions, the underlying sediments are aeolian sands, the groundwater levels are very low, and there are few rivers to support irrigation systems in farmland. Therefore, limitations of water resources controlled the desertification processes in these regions.

The decreased water inflows into this region directly resulted in rapid desertification. From the mid-1970s to the mid-1990s, there was no significant change in the area of farmland (Fig. 10), but the areas of anchored and semi-anchored dunes decreased and the area of semi-mobile dunes increased. This suggests that vegetation degradation on these dune surfaces accompanied the decrease in groundwater levels. However, the area of mobile dunes decreased after the mid-1990s as a result of a significant decrease in sand transport; this occurred because the period from the mid-1990s to the present had the lowest wind activity during the past 50 years in arid and semiarid China (Wang et al. 2006).

Over the past 2,000 years, humans have, of course, played a role in environmental changes in this region. Historical records show that the population of the Minqin Oasis and its adjacent areas neared 150,000 in 500 A.D., and exceeded 200,000 by the early 1900s (Wang et al. 2003). In comparison, the populations between 1912 and 1949 and between 1949 and 2002 averaged about 200,000 (Sun 2004) and 350,000, respectively. About 99% of population lived within the oasis, which suggests that the oasis provides the largest parts of food and other materials for the region's population. However, this data does not prove that flourishing of agriculture was the principal contributor to desertification in the region. Although extensive reclamation was carried out from the 1900s to the present in this region, the approach used during this period was still similar to those that have been used throughout the past 2,000 years: lands with the best moisture conditions were reclaimed, and were abandoned again during periods when water was limited. Although decreasing lake levels may have provided more land with suitable moisture conditions for farming during some periods, the reclaimed oases were soon abandoned because it was very difficult to acquire enough water for irrigation due to the overall trend of decreasing lake levels and increasingly arid climate from the mid-Holocene to the present (Chen et al. 2003).

We have developed generalized frameworks that represent the variations in precipitation, evaporation, sand-

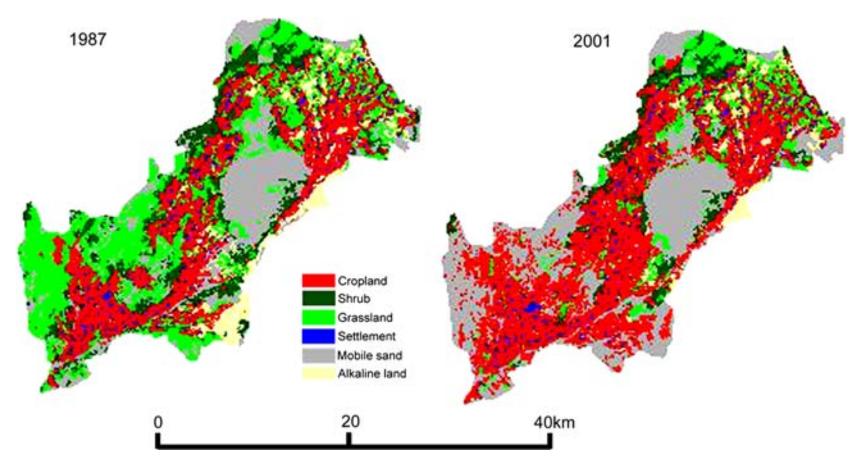


Fig. 9 Distributions of farmland in 1987 and 2001 in the Minqin Oasis. Data are from Li et al. (2005)

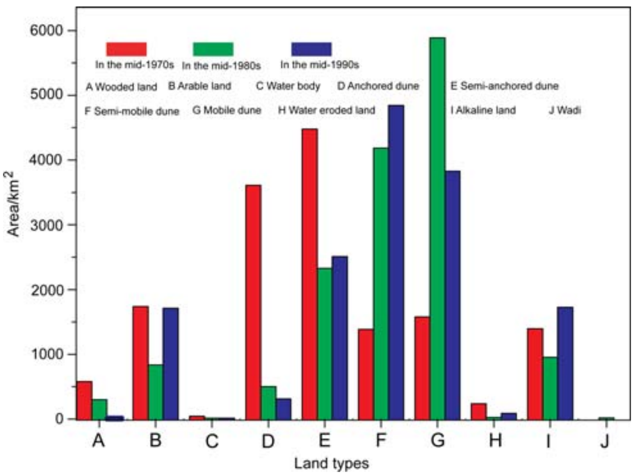


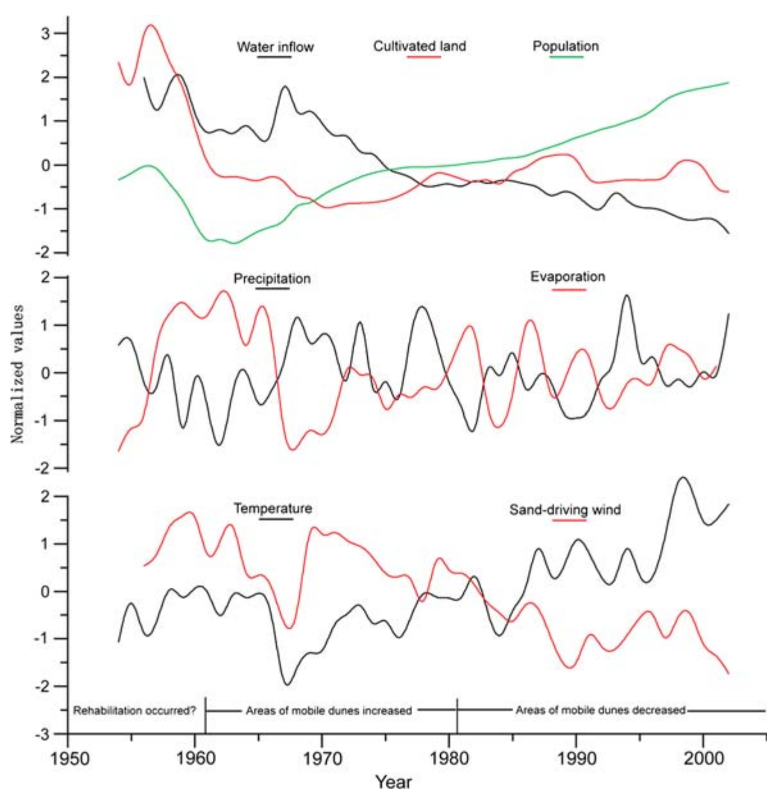
Fig. 10 Areas in different landscape categories in the mid-1970s, mid-1980s, and mid-1990s in the Minqin Oasis. Data are from Wang et al. (2004a, b)

driving winds, water inflow, and proxies for human activity (population size and area of farmlands) over the past 50 years to assess their roles in desertification in the Minqin Oasis (Fig. 11). This framework suggest that although the vulnerability to desertification is a function of anthropogenic pressures, geomorphological processes, and climate change, in the Minqin Oasis and the surrounding region, water resource limitations have been more important. Many previous studies (e.g., Hou 1973; Wang et al. 2004a, b) have suggested that desertification in North China has been primarily the product of human activity, and government policies that encouraged reclamation have also accelerated desertification to some extent, but the detailed analysis presented in this paper does not support the hypothesis that the flourishing of agriculture in the region was principally responsible for desertification. In the Minqin Oasis and its adjacent regions, human activities may have contributed to desertification, but do not appear to have been the principal control, despite the evidence from previous studies.

Conclusions

Over the past 7000 years the Minqin Oasis and its adjacent regions have experienced significant environmental changes, and long-term trends towards an increase in the aridity seem to have been primarily responsible for desertification in the region. The evolution of the Minqin Oasis was mainly controlled by variations in the water component of the ecosystem, and these variations have primarily resulted from long-term climatic changes. Lake levels decreased continuously from about 400 B.C. to the present, and the area of the oasis increased during some periods because the wadis left behind as the lakes retreated provided fine-grained materials and high groundwater levels that were suitable for farming. However, as groundwater levels and

Fig. 11 A conceptual diagram of a framework for trends in population size, water inflows, the area of farmland, evaporation, temperature, sand-driving wind, and precipitation, and the relationship of these indices to three periods of desertification in the Minqin Oasis



water inflows decreased, sandy desertification was inevitable in the region irrespective of whether the land was reclaimed for agriculture. From 1949 to the present, although the population and the area of reclaimed oasis reached the highest levels reported for the past 2,000 years, and the overuse of water in the upstream over the past 50 years accelerated desertification, the current trend towards desertification appears to be the continuation of a process that began in the mid-Holocene, and that has mainly been controlled by climate change and geomorphological processes.

Additional issues should be resolved before we blame desertification in this region and possibly in the rest of arid China on human activities such as over-reclamation and over-grazing. Humans may be responsible for exacerbating desertification, but do not appear to be the key factor in initiating desertification. Geomorphological and climatic analyses, and review of historical records from ancient China all suggest that rehabilitation may have occurred in this region during periods when there was sufficient water available for agricultural uses, as appears to have been the case 300 years ago. However, it seems unlikely that abundant water supplies will once again be available in this region because the abundant water supplied to the region 6,000 years ago has become exhausted due to the sustained arid climate that began in the mid-Holocene period.

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