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IMPACT OF LAND USE AND LAND COVER CHANGE ON ENVIRONMENTAL DEGRADATION IN LAKE QINGHAI WATERSHED, NORTHEAST QINGHAI-TIBET PLATEAU

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ABSTRACT

Lake Qinghai, the largest saline lake in China, covers 4234 km^2 (2007) with a catchment area of 29 660 km^2 on the northeastern margin of the Qinghai-Tibet Plateau. The ecosystem of the lake is extremely vulnerable and sensitive to global climate change and human interference. However, little information is available on land use/cover change (LUCC) in Lake Qinghai watershed. Using a geographical information system (GIS) and remote sensing (RS), this study analysed land use and land cover change pattern in Lake Qinghai watershed between 1977 and 2004 and discussed major environmental issues in this area. LUCC analysis indicated that grassland (63 per cent) and water body (18 per cent) dominated in the watershed and the magnitude of the land use and land cover change was generally low; the percentage of the change of various land types relative to the total area was less than 1 per cent. From 1977 to 2004, cropland, sandy land, bare rock, salinized land, swampland and built-up areas increased by 0·43, 0·35, 0·24, 0·06, 0·03 and 0·03 per cent of the total area, respectively; in contrast, water body, grassland and woodland decreased by 0·99, 0·22 and 0·05 per cent, respectively. Moreover, the area of LUCC tended to expand from places around the lake to the upper reaches of the watershed during the last three decades. The LUCC transition pattern was: woodland converted to grassland, grassland converted to cropland and water body converted to sandy land. Lake level decline and grassland degradation are major ecological and environmental problems in Lake Qinghai watershed. The level and area of the lake decreased at the rate of 6·7 cm a^{-1} and 6·4 $km^2\ a^{-1}$, respectively, between 1959 and 2007, resulting in sandy land expansion and water quality deterioration. Lake level decline and area shrinkage was mainly attributed to climate change, but grassland degradation was mainly resulted from anthropogenic activities (increasing population, overgrazing and policy). Copyright © 2008 John Wiley & Sons, Ltd.

KEY WORDS: land use/cover change; Lake Qinghai; lake level; grassland; P.R. China

INTRODUCTION

Land use/cover change (LUCC) has important impacts on the functioning of socio-economic and environmental systems with important tradeoffs for sustainability, food security, biodiversity and the vulnerability of people and ecosystems to global change impacts (Lesschen *et al*., 2005). Land cover change refers to the complete replacement of one cover type by another, for example deforestation. Land use change includes the modification of land cover types, for example intensification of agricultural management or other changes in the farming system. Land use and land cover changes are the result of the interplay between socio-economic, institutional and environmental factors

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(Lesschen *et al*., 2005). LUCC has become a major area of research, especially since the International Geosphere and Biosphere Programme (IGBP) and the International Human Dimensions Programme on Global Environmental Change (IHDP) initiated their core project on land use and cover change in the mid-1990s (Turner *et al*., 1995; Lambin *et al*., 1999).

China has experienced obvious land use change since last century. Regional land use changes in the eastern developed regions of China have received great attention; comparatively, land use changes in its western undeveloped regions have attracted little attention, especially on the frigid and arid Qinghai-Tibet Plateau, where both economic development and arid environmental changes strongly affect land use change (Wang *et al*., 2008). Lake Qinghai, the largest saline inland lake with an area of 4234 km^2 (in 2007) at an elevation of 3193 m, is located in the northeastern Qinghai-Tibet plateau. The lake is extremely sensitive to climate changes because it lies in a critical transitional zone, where the East Asian summer monsoon, Indian summer monsoon, winter monsoon and the westerly jet stream prevail (Xu *et al*., 2006). In the recent decades, the lake has experienced severe declines in water level and its watershed suffered from a series of environmental problems (grassland degradation, wetland shrinkage, biodiversity reduction, desertification expansion and lake water deterioration) (Li *et al*., 2007). Thus the lake has attracted much attention worldwide and it becomes a hot place for research of climate changes and environmental issues (Hao, 2008). For example, Lake Qinghai Drilling Project of International Continental Scientific Drilling Program is being in progress (An *et al*., 2006). Recently, a 10-year plan on environmental restoration in Lake Qinghai watershed has been initiated (Hao, 2008).

The ecological issues affecting Lake Qinghai are complex, the driving forces are mainly resulted from natural (climatic) and anthropogenic factors. However, information concerning human activities (e.g. LUCC) is scarce in this area, therefore, it is necessary to know land use change and its possible effects on ecological degradation in the lake watershed. The objectives of the study were to analyse land use and land cover changes in Lake Qinghai watershed between 1977 and 2004 using geographical information system (GIS) and remote sensing (RS), and to discuss major environmental issues in this area. This would help us to have a better understanding of the effect of human activity on the processes of land degradation in the past and may enable the improvement of future planning strategies.

STUDY AREA

Lake Qinghai lies in a closed intermountain basin between 36°32′–37°15′N and 99°36′–100°47′E (Figure 1), which is situated in the semiarid, cold and high altitude climate zone. The mean annual temperature, precipitation and evaporation are −0·7°C, 250 and 800–1000 mm, respectively (Shen *et al*., 2005). The climate of the lake is mainly influenced by three air masses: East Asian monsoon, Indian monsoon and westerly atmospheric flow. There are distinctive seasonal shifts associated with a monsoonal climate in Lake Qinghai basin (Qin and Huang, 1998). In the winter, in the upper atmosphere westerlies prevail and in the lower atmosphere the polar cold air mass prevails. The weather is clear, dry, cold and windy. In the summer, the Asiatic depression is over the Qinghai-Tibetan Plateau and the subtropical anticyclone (STA) is displaced northward to 30°N with massive moisture precipitating in East Asia. The condition is warm and wet. About 70–80 per cent of the annual rainfall occurs in the summer and early autumn.

Lake Qinghai is a closed-catchment lake with no surface water outflow. The whole catchment area is 29 660 km^2. The lake is surrounded by a few mountains: Datong Mt., Riyue Mt. and South Qinghai Mt. (Figure 1). Vegetation is dominated by montane shrub and alpine meadow in the catchment. There are virtually no forests in the basin, only a limited area of desert, and some irrigated farmland to the north and northeast of the lake. The orography of the basin runs from northwest to southeast. The highest part of the basin is located in the northwest and reaches more than 5000 m above sea level. More than 40 rivers flow into Lake Qinghai, but most are intermittent. Five of the inflows contribute 83 per cent of the total runoff. The longest and greatest river is Buha River, with a discharge of $7{\cdot}85 \times 10^8\ m^3\ a^{-1}$, equal to almost half of the total runoff; the second river is Shaliu River with a discharge of $2{\cdot}46 \times 10^8\ m^3\ a^{-1}$, 14·5 per cent of the total runoff to the lake.

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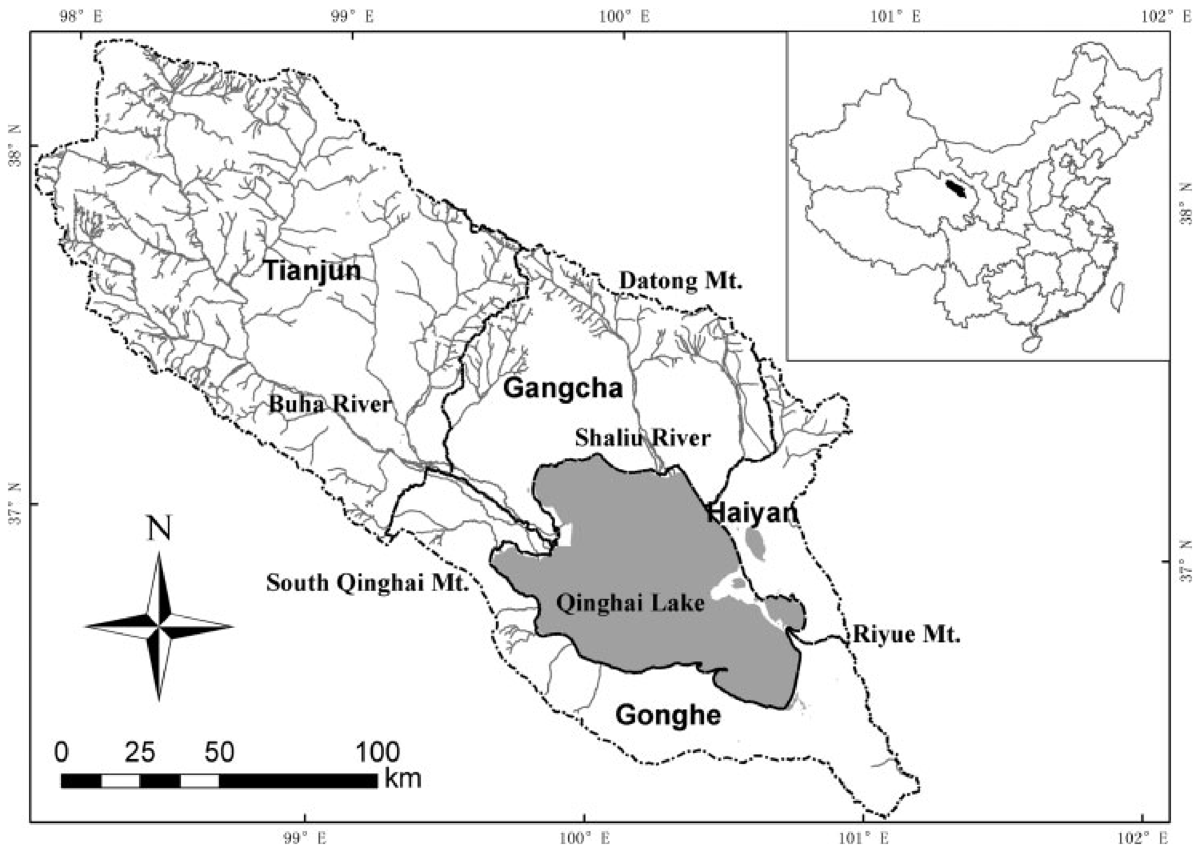

Figure 1. Location and sketch map of Lake Qinghai watershed.

DATA AND METHODS

Database

Using EARDS IMAGE® 8.5 and ARC/INFO® 9.0 software, the four periods of remote-sensing data including the 1977 Landsat MSS data and the 1987 Landsat TM data and the 2000 and 2004 Landsat ETM data in August, were converted to images based on the 1:100 000 topographic map. The Landsat images were enhanced using the linear contrast stretching and histogram equalization to help identify ground control points in the rectification to a common ALBERS coordinate system. The land use classification was conducted through visual interpretation to guarantee the consistency and accuracy of data processing. Field survey and random sample check show that interpretation accuracy was 100 per cent for shrub and steppe areas, 95 per cent for agriculture and settlements and 90 per cent for barren and degraded lands, with an overall interpretation accuracy of 97 per cent. The maps were analysed using the overlaying and intersecting operations to derive LUCCs and spatial distribution.

According to the classification system of national land-use status (Liu *et al.*, 2005) and land-use characteristics in Lake Qinghai watershed, a hierarchical classification system of 21 land-cover subclasses was applied to the Landsat MSS/TM/ETM data. The 21 subclasses of land cover were further grouped into 6 aggregated classes of land cover: cropland, woodland, grassland, water bodies, unused land and built-up area. Croplands consisted of mountainous and plain croplands. Woodland included forest, shrub and orchard. Grassland included three density-dependent types: higher coverage grassland, medium coverage grassland and lower coverage grassland. Water bodies included stream and rivers, lakes, glacier and firn and bottomland (overflow land). Unused land included sandy land,

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Table I. Land use types and their descriptions in Lake Qinghai watershed

Land use types	Description
Dry cropland	Rainfed cropland without water supply and irrigating facilities
Dense forest	Woodland with a crown density >30 per cent
Scrubland	Scrubland with a crown density >40 per cent and height less than 2 m
Sparse forest	Woodland with a crown density of 10–30 per cent
Higher coverage grassland	Grassland with a coverage >50 per cent
Medium coverage grassland	Grassland with a coverage between 20 and 50 per cent
Lower coverage grassland	Natural grassland with a coverage of 5–20 per cent
Stream and rivers	Lands covered by rivers including canals
Lakes	Lands covered by lakes
Glacier and firn	Lands covered by perennial snowfields and glaciers
Overflow land	Flood-affected land on riverside or lakeside
Built-up land	Residential area and land used for factories or mining sites
Sandy land	Land covered with sand, vegetation coverage <5 per cent
Salinized land	Lands with salt accumulation and sparse vegetation
Swampland	Lands with a permanent mixture of water and herbaceous or woody vegetation that cover extensive areas
Bare soil	Bare exposed soil with less than 5 per cent vegetation cover
Bare rock	Bare exposed rock with less than 5 per cent vegetation cover

salinized land, bare soil, bare rock, swampland and tundra. Built-up lands included roads as well as residential and industrial areas, the detail descriptions of some land use types are listed in Table I (Liu *et al.*, 2005; Wang *et al.*, 2008).

Methods

The patterns and processes of LUCC were described by land use change rate and transition rate in the study.

Land use change rate for a single land use type during different periods was assessed by the following formula (Chen, 1998; Wang and Bao, 1999):

$$K = \frac{U_{\mathrm{b}} - U_{\mathrm{a}}}{U_{\mathrm{a}}} \times \frac{1}{T} \times 100\%$$

where K is land use change rate for a single land use type (per cent), U_{a} and U_{b} are the areas of the land-use type at the beginning and at the end for a period, respectively. T is time intervals (years).

Comprehensive land use change rate for the integrated all land use types during different periods was assessed by the following formula (Chen, 1998; Wang and Bao, 1999):

$$\mathrm{LC} = \frac{\sum_{i=l}^{n} \Delta \mathrm{LU}_{i-j}}{2 \times \sum_{i=l}^{n} \mathrm{LU}_i} \times \frac{1}{T} \times 100\%$$

where LC is comprehensive land use change rate (per cent), LU_i is the area of the ith land-use type at the beginning, $\Delta\mathrm{LU}_{i-j}$ is the area of the ith land-use type converted to the jth land-use type.

The matrixes of transition probabilities of land-use types in different periods were established and were then used to analyse the transition rate from one land use type into another for the periods 1977–1987, 1987–2000 and 2000–2004. Each matrix represents either the probability of persistence of each category of land use/cover from the first to the last year of the period, or the probabilities of transition to another land-cover category during the same period. Matrix values were standardized to obtain annualized change values. The procedure for standardization of matrices

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to assess land-cover change was proposed by Rovainen (1996) in order to make comparisons based on annual values when the information derives from several different time intervals.

RESULTS AND DISCUSSION

Land Use and Land Cover Change

Based on the analysis of the three land use/cover maps for the periods of 1977–1987, 1987–2000 and 2000–2004 (Figure 2), the area of the main land use/cover classes for the four time periods was assessed (Table II). The individual subclasses of the unused land class are listed in Table II because sandy land and bare rock had experienced great changes. Table II indicates that land use/cover types were mainly dominated by grassland and water body, which accounted for about 63 and 18 per cent of the total area, respectively. From 1977 to 2004, cropland, sandy land, bare rock, salinized land, swampland and built-up areas increased by 0·43, 0·35, 0·24, 0·06, 0·03 and 0·03 per cent of the total area, respectively; in contrast, water body, grassland and woodland decreased by 0·99, 0·22 and 0·05 per cent, respectively. Although the variation amplitude of land use pattern for various classes was not great, the results suggest that area of the land types for ecological use (water body, grassland and woodland)

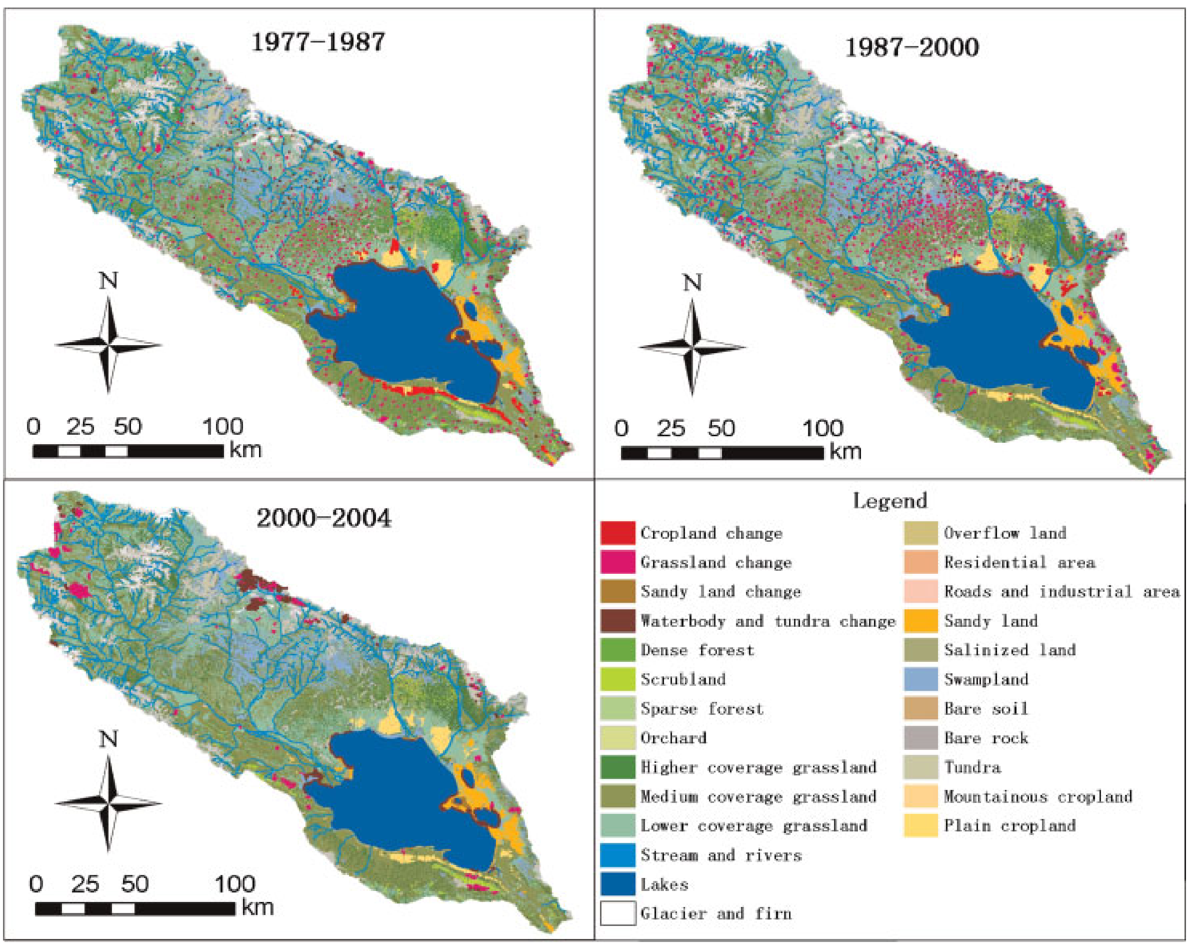

Figure 2. Land use and land cover change in Lake Qinghai watershed during the period of 1977–1987, 1987–2000 and 2000–2004. This figure is available in colour online at www.interscience.wiley.com/journal/ldr.

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Table II. Land use/cover change in Lake Qinghai watershed as extracted from Landsat images 1977–2004

Year	Area and percentage	Cropland	Woodland	Grassland	Water body	Built-up areas	Sandy land	Salinized land	Swampland	Bare soil	Bare rock	Tundra
1977	km^2	321·87	519·59	18 995·15	5500·24	7·93	562·36	28·01	2327·07	0·15	189·47	1238·70
	%	1·08	1·75	63·98	18·53	0·03	1·89	0·09	7·84	0·00	0·64	4·17
1987	km^2	414·50	510·83	18 941·52	5393·68	14·41	619·37	41·85	2323·79	0·15	189·90	1240·55
	%	1·40	1·72	63·80	18·17	0·05	2·09	0·14	7·83	0·00	0·64	4·18
2000	km^2	444·79	503·88	18 896·99	5360·84	17·48	656·32	45·15	2330·35	0·15	189·54	1245·29
	%	1·50	1·70	63·65	18·06	0·06	2·21	0·15	7·85	0·00	0·64	4·19
2004	km^2	448·54	503·64	18 930·44	5207·47	18·56	665·17	45·31	2335·44	0·15	262·15	1273·92
	%	1·51	1·70	63·76	17·54	0·06	2·24	0·15	7·87	0·00	0·88	4·29
1977–2004	km^2 change	126·67	−15·95	−64·71	−292·77	10·64	102·81	17·30	8·37	0·00	72·68	35·22
	% change	0·43	−0·05	−0·22	−0·99	0·03	0·35	0·06	0·03	0	0·24	0·12

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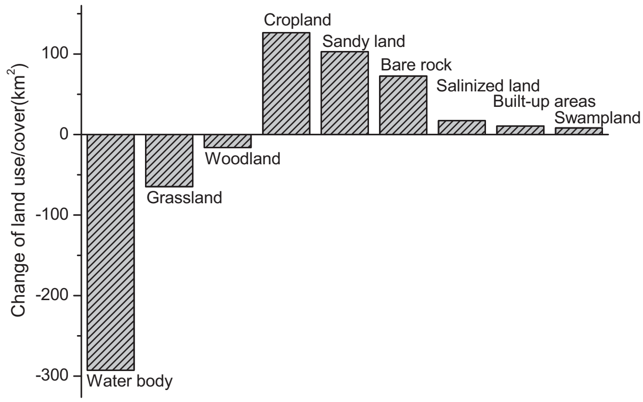

Figure 3. Area changes of the different types of land use and land cover between 1977 and 2004.

tended to decrease, but the area of the land types for agricultural production and human residence tended to increase (Figure 3), indicating that anthropogenic influences on LUCC have being increasing during the recent three decades. It is interesting to note that water body recorded the largest net decrease of 293 km^2 from 5500 km^2 in 1977 to 5207 km^2 in 2004; of which the lake area deceased by 178·6 km^2, and glacier and firn area by 128·6 km^2. There is no obvious change for river area but the bottomland area increased by 13·1 km^2.

LUCC rate in Table III indicates that significant LUCC occurred between 1977 and 1987, particularly for cropland, built-up areas and sandy land, and the intensity decreased in the two periods of 1987–2000 and 2000–2004. However, the intensity of decreasing rate for water body increased with years. For the grassland, the area decreased between 1977 and 2000; but it increased between 2000 and 2004. This was mainly because the government launched the 'grain to green' programme to return croplands not suitable for agriculture to forests or grasslands for environmental restoration (Hao, 2008). We also noted that the area of LUCC tended to expand from the places around the lake to the upper reaches of the watershed during the last three decades; and the main land use types with great changes were cropland, grassland and water body for the period of 1977–1987, 1987–2000 and 2000–2004, respectively (Figure 2).

LUCC Transition Matrices

The probabilities of change were obtained from the transition matrices corresponding to the periods 1977–1987, 1987–2000 and 2000–2004 (Table IV). During the first period between 1977 and 1987, the class water body showed great transition as compared to the other classes. Most of the transformed water body was converted to sandy land (60·85 km^2, 1·1 per cent), 0·5 per cent converted to other unused land and 0·34 per cent converted to grassland. Grassland also experienced great conversion between 1977 and 1987, 0·54 per cent (102·05 km^2) was changed into cropland, and the remainder were mainly converted to built-up areas (4·07 km^2) and salinized land (4·22 km^2). Woodland showed minimal changes, only 8·76 km^2 converted to grassland. The unused land keep great persistence within the same class except only a small part of sandy land converted to salinized land. During the periods of 1987–2000 and 2000–2004, LUCC dynamics were weakened as compared to the period of 1977–1987. In general, the LUCC transition pattern in Lake Qinghai watershed was: woodland converted to grassland, grassland converted to cropland and water body converted to sandy land. However, during the period of 2000–2004, 50·40 km^2 water body, 8·88 km^2 sandy land, 15·30 km^2 swampland and 24·13 km^2 tundra converted to grassland.

Effect of LUCC on Environmental Degradation

Lake level decline is the most important ecological and environmental issue in the region. During 1977–2004, water body experienced noticeable shrinkage. Data analysis from hydrological stations indicated that the area of Lake Qinghai has shrunk from 4401 km^2 in 1977 to 4186 km^2 in 2004, and correspondingly, the lake level decreased from

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Table III. Land use/cover change rate during different periods between 1977 and 2004 (per cent)

Period	Land use/cover change rate for a single land use type											Comprehensive land use change rate
	Cropland	Woodland	Grassland	Water body	Built-up area	Sandy land	Salinized land	Swampland	Bare soil	Bare rock	Tundra	
1977–1987	2.88	−0.17	−0.03	−0.19	8.18	1.01	4.94	−0.01	0.00	0.02	0.01	0.05
1987–2000	0.56	−0.10	−0.02	−0.05	1.64	0.46	0.61	0.02	0.00	−0.01	0.03	0.02
2000–2004	0.21	−0.01	0.04	−0.72	1.54	0.34	0.09	0.05	0.00	9.58	0.57	0.12

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Table IV. Transition matrix of land use change processes in Lake Qinghai watershed from 1977 to 2004 (km^2)

Year		Cropland	Woodland	Grassland	Water body	Built-up area	Sandy land	Salinized land	Swampland	Bare soil	Bare rock	Tundra	Total
1977/1987	Cropland	312·46	0·00	7·09	0·00	2·31	0·00	0·00	0·00	0·00	0·00	0·00	321·87
	Woodland	0·00	510·83	8·76	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	519·59
	Grasslands	102·05	0·00	18 878·78	0·17	4·07	1·81	4·22	2·20	0·00	0·42	1·43	18 995·15
	Water body	0·00	0·00	18·59	5393·55	0·00	60·85	3·97	23·28	0·00	0·00	0·00	5500·24
	built-up areas	0·00	0·00	0·00	0·00	7·93	0·00	0·00	0·00	0·00	0·00	0·00	7·93
	Sandy land	0·00	0·00	0·00	0·00	0·00	556·70	5·65	0·00	0·00	0·00	0·00	562·36
	Salinized land	0·00	0·00	0·00	0·00	0·00	0·00	28·00	0·00	0·00	0·00	0·00	28·01
	Swampland	0·00	0·00	28·32	0·00	0·10	0·00	0·00	2298·30	0·00	0·00	0·34	2327·07
	Bare soil	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·15	0·00	0·00	0·15
	Bare rock	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	189·47	0·00	189·47
	Tundra	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	1238·70	1238·70
	Total	414·51	510·83	18 941·55	5393·72	14·41	619·36	41·85	2323·78	0·15	189·89	1240·47	/
1987/2000	Cropland	413·07	0·00	0·22	0·00	1·21	0·00	0·00	0·00	0·00	0·00	0·00	414·50
	Woodland	0·00	503·88	5·15	0·00	0·07	0·00	0·00	1·73	0·00	0·00	0·00	510·83
	Grasslands	31·72	0·00	18 873·04	1·16	1·79	14·17	1·94	13·47	0·00	0·00	4·24	18 941·52
	Water body	0·00	0·00	3·15	5359·66	0·00	23·80	0·91	6·15	0·00	0·00	0·00	5393·68
	built-up areas	0·01	0·00	0·00	0·00	14·40	0·00	0·00	0·00	0·00	0·00	0·00	14·41
	Sandy land	0·00	0·00	0·75	0·00	0·00	618·17	0·45	0·00	0·00	0·00	0·00	619·37
	Salinized land	0·00	0·00	0·00	0·00	0·00	0·00	41·85	0·00	0·00	0·00	0·00	41·85
	Swampland	0·00	0·00	13·86	0·00	0·01	0·00	0·00	2309·00	0·00	0·92	0·00	2323·79
	Bare soil	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·15	0·00	0·00	0·15
	Bare rock	0·00	0·00	0·37	0·00	0·00	0·00	0·00	0·00	0·00	189·53	0·00	189·90
	Tundra	0·00	0·00	0·35	0·00	0·00	0·00	0·00	0·00	0·00	0·00	1240·20	1240·55
	Total	444·79	503·88	18 896·90	5360·82	17·48	656·14	45·15	2330·34	0·15	190·45	1244·44	/
2000/2004	Cropland	443·89	0·00	0·22	0·00	0·68	0·00	0·00	0·00	0·00	0·00	0·00	444·79
	Woodland	0·00	501·19	0·89	0·00	0·00	0·00	0·00	0·00	0·00	0·00	1·81	503·88
	Grasslands	4·24	2·40	18 829·28	0·38	0·80	1·55	0·00	0·87	0·00	6·00	51·48	18 896·99
	Water body	0·00	0·00	50·40	5204·54	0·00	18·55	0·25	16·82	0·00	67·81	2·47	5360·84
	built-up areas	0·41	0·00	0·00	0·00	17·08	0·00	0·00	0·00	0·00	0·00	0·00	17·48
	Sandy land	0·00	0·00	8·88	2·38	0·00	645·06	0·00	0·00	0·00	0·00	0·00	656·32
	Salinized land	0·00	0·00	0·09	0·00	0·00	0·00	45·06	0·00	0·00	0·00	0·00	45·15
	Swampland	0·00	0·01	15·30	0·01	0·00	0·00	0·00	2314·20	0·00	0·06	0·77	2330·35
	Bare soil	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·00	0·15	0·00	0·00	0·15
	Bare rock	0·00	0·00	1·26	0·00	0·00	0·00	0·00	0·00	0·00	188·28	0·00	189·54
	Tundra	0·00	0·04	24·13	0·17	0·00	0·00	0·00	3·55	0·00	0·00	1217·40	1245·29
	Total	448·54	503·64	18 930·44	5207·47	18·56	665·17	45·31	2335·44	0·15	262·15	1273·92	/

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3194·91 m in 1977 to 3192·77 m in 2004. Figure 4 shows variation of area and level of the lake between 1959 and 2007, the level and area of the lake decreased at the rate of 6·7 cm and 6·4 km^2 per year, respectively. Qin and Huang (1998) reported that, the area of Lake Qinghai was 4980 km^2 in 1908, hence the area reduced by 746 km^2 during the recent 99 years. Moreover, the shape of the lake varied significantly and several small satellite lakes were isolated from the parent lake (Figure 5), the shoreline had shrunk 4047, 2367 and 1311 m on Sandy Island of the east bank, Bird Island of the west bank and Shaliu River of the north bank, respectively, from 1977 to 2004, and the corresponding average annual shrinking rate of the shorelines were 150, 88 and 49 m a^{-1}, respectively (Figure 5 and Table V).

Decline in lake level exposed lake sediments to the air, and these sediments would be blown away by wind during dry periods, resulting in serious wind erosion (Sun *et al*., 2008). Mean annual wind speed is 3·6 m s^{-1} and the highest wind speed is 26·7 m s^{-1} in the lake area based on 30-year meteorological records; on average, there were 16 strong wind (>17 m s^{-1}) days and 5 dust storm days in the area. Sandy land formed around the lake where lake water shrunk (Figure 6). Table VI indicates that sandy land expanded 3765, 1858 and 1244 m on Sandy Island of the east bank, Bird Island of the west bank and Shaliu River of the north bank, respectively, from 1977 to 2004. Zhang *et al*. (2003) estimated that about $8{\cdot}87 \times 10^6$ ton aeolian sand was blown into the lake annually. Decline in lake level also led to deterioration of the water quality and decrease in water supplies, the salinity of lake water increased from 12·49 to 15·33 per cent from 1960 to 2003, and pH increased from 9·0 to 9·2 (Li *et al*., 2007), Yu (1996) reported that the degree of mineralization of Lake Qinghai was 14·45 g L^{-1} and increased as lake shrunk and climate became dry. The chemical component concentration of Ca^{2+}, Mg^{2+}, CO_3^{2-} and SO_4^{2-} tended to decrease and of Na^+, K^+ and Cl^- tended to increase. These would deteriorate surroundings of fish and bird, and therefore biodiversity drops significantly (Liu *et al*., 2007a).

Grassland degradation was another important ecological and environmental issue in Lake Qinghai watershed. Interpretation of RS images indicated that higher coverage grassland and medium coverage grassland decreased by 128 km^2 (0·4 per cent) and 91 km^2 (0·3 per cent), respectively, from 1977 to 2004, while lower coverage grassland increased by 155 km^2 (0·5 per cent). This suggests that although there were small changes in the quantity of the area of grassland, the quality of the grassland substantially dropped. Fu *et al*. (2008) reported that grass yield was 6056 kg ha^{-1} in 1989, but it varied between 1747 and 2450 kg ha^{-1} at present; the annual decreasing rate was about 84 kg ha^{-1} a^{-1}. Grassland degradation in this region is caused primarily by overgrazing by yaks and sheep and together with locust- and rat-induced destruction. At present, the severely degraded grassland totals 182 600 ha in the lake area (Zhang *et al*., 2006). Grazing-induced degradation is especially severe during early winter and late spring (Liu *et al*., 2004).

Driving Forces of Land Use Change

LUCCs are resulted from natural (climatic) and anthropogenic factors. A growing body of evidence suggests that climate change is more important than human activity in changing water levels (Fan and Shi, 1992; Ding and Liu, 1995; Ma, 1996; Qin and Huang, 1998; Li *et al*., 2007; Liu *et al*., 2007a, 2008; Hao, 2008; Shu *et al*., 2008). Liu *et al*. (2007b) and Sun (2008) simulated the effects of climate change and LUCC on runoff of the Buha River and Shaliu River in Lake Qinghai watershed using Soil and Water Assessment Tool (SWAT) model, and concluded that more than 80 per cent of variation of the runoff in the watershed was attributed to climate change. Li *et al*. (2007) analysed water balance of Lake Qinghai and found that mean annual evaporation from the lake was 924 mm, while water consumption by human accounts for only a very small part of the evaporation loss (1 per cent) of the lake, suggesting that the change of lake level depends mainly on climatic factors. Qin and Huang (1998) reported that water level of Lake Qinghai was sensitive to the climatic changes in both temperature and precipitation. However, the effects of precipitation on lake level were always counteracted by the rise or fall in temperature. The lake level trend was determined by the balance of precipitation and temperature because changes in precipitation affected the surface runoff inflow to the lake whereas the changes in temperature affected evaporation through the out-flux of lake water (Li *et al*., 2007). Statistics showed that the most dramatic decline in lake level occurred in the warm and dry years, and moderate decline in the cold and dry years, and relatively slight decline in the warm and wet years; in contrast, water storage in the lake tended to increase and lake level rose in the cold and wet years. Therefore, Li

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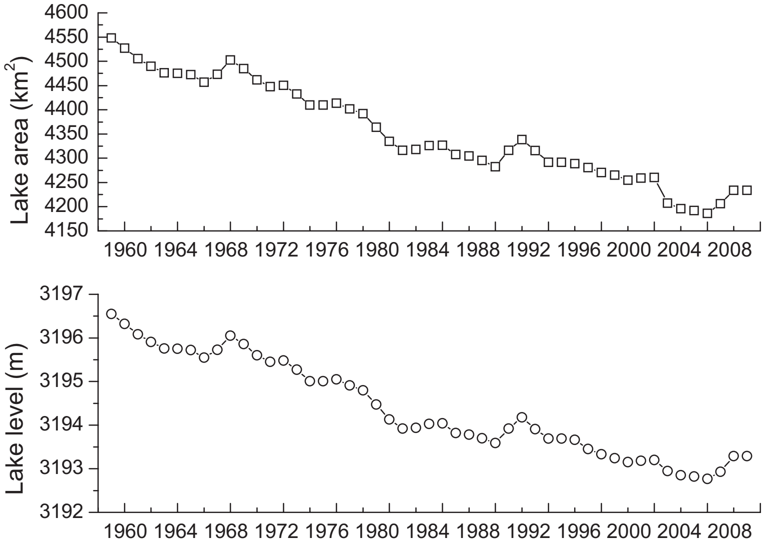

Figure 4. Variation of water level and area of Lake Qinghai between 1959 and 2007.

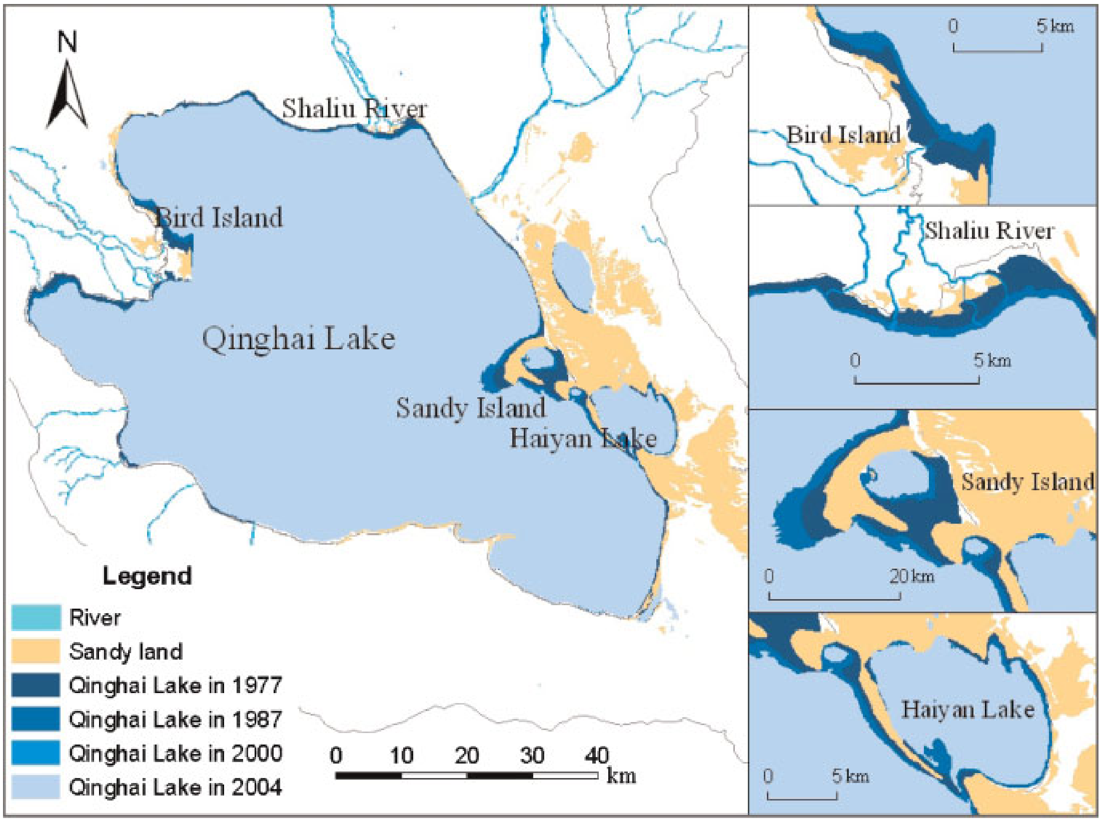

Figure 5. Shrinkage of water body of Lake Qinghai between 1977 and 2004. This figure is available in colour online at www.interscience.wiley.com/journal/ldr.

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Table V. Distance of shoreline shrinkage around Lake Qinghai between 1977 and 2004 (m)

Period	Sandy Island	Shaliu River	Bird Island	Haiyan
1977–1987	1980.6	934.6	1457.7	479.9
1987–2000	1157.7	264.0	580.87	123.5
2000–2004	908.7	112.5	327.8	75.3
1977–2004	4047.0	1311.1	236.4	678.7

et al. (2007) pointed out the trend of warm and dry climate might be the main reasons for the decline in lake level in the recent decades. According to studies of Fan and Shi (1992), lake level would increase by 8·7 cm when precipitation increases by 10 per cent and temperature keep constant; in contrast, lake level would decrease by 16·4 cm when temperature increases by 1°C and precipitation keeps constant. In Lake Qinghai watershed, mean annual air temperature increased with a rate of 0·31°C per decade from 1961 to 2007 (Figure 7), particularly the ascending tendency of air temperature was remarkably in winter with an increasing rate of 0·53°C per decade (Xu *et al*., 2007). The increasing magnitude of air temperature is obviously greater than the global average (0·13 ± 0·03°C per decade) (Trenberth *et al*., 2007). There was a slight increasing trend for precipitation (4·2 mm per decade) but it was not statistically significant; the inter-annual variation of precipitation was significant, there

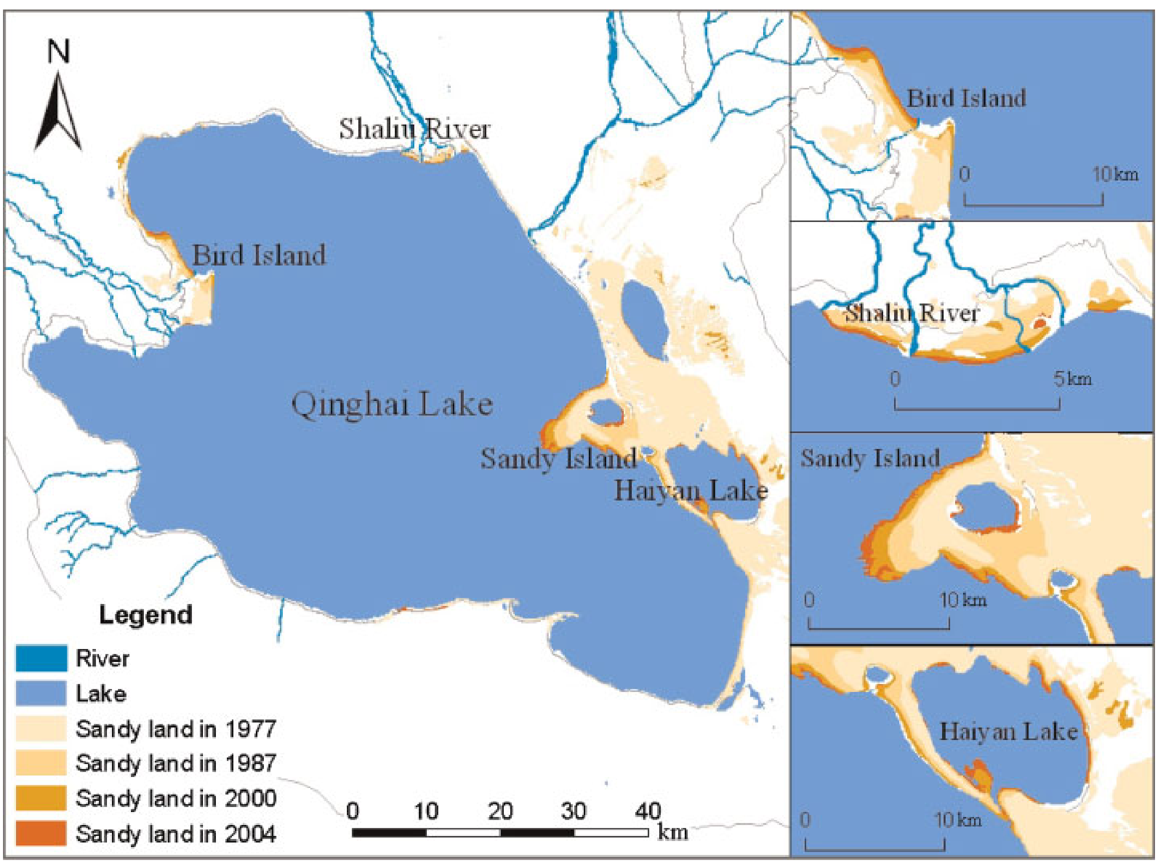

Figure 6. Sandy land expansions around Lake Qinghai between 1977 and 2004. This figure is available in colour online at www.interscience.wiley.com/journal/ldr.

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Table VI. Advance distances of sandy land expansion around the lake between 1977 and 2004 (m)

Period	Sandy Island	Shaliu River	Bird Island	Haiyan
1977–1987	1877.8	895.3	870.3	624.0
1987–1000	1088.5	242.5	643.4	156.6
2000–2004	798.3	105.9	343.8	70.9
1977–2004	3764.6	1243.7	1857.5	851.5

were ascending tendencies during the 1960s, 1980s and 1990s, while precipitation in the 1970s showed downward trend (Figure 7). In recent 3 years, lake level rebounded due to increasing precipitation (Figure 4). Liu *et al*. (2008) and Shu *et al*. (2008) modelled that lake levels likely will fluctuate from 2006 to about 2010 and then rebound in the future 30 years.

Grassland degradation was mainly resulted from anthropogenic factors. In this predominantly grazing region, excessive reliance on animal husbandry under a growing population has exerted great pressure on the land (Liu *et al*., 2004). The total population in Lake Qinghai watershed was less than 20 000 in 1949, but it increased to 85 600 in 2004; more than fourfold increase in population in recent 50 years resulted in 20-fold increase in area of croplands. Correspondingly, the total amount of animal husbandry was 4·22 million sheep units in 2004, which was 2·9 times of that in 1949. The maximum carrying capacity in theory was 2·13 million sheep units in the watershed, so overgrazing rate amounted to 98 per cent, this would lead serious grassland degradation (Zhang *et al*., 2006; Liu *et al*., 2008). Moreover, tourism developed quickly in recent years, there are about more than 0·8 million travellers per year come to Lake Qinghai, this would not only disturb grassland but also affect biodiversity (Zhang *et al*., 2006).

National policy strongly affected LUCCs in Lake Qinghai watershed. Most grassland was reclaimed to cropland under the policy of 'reclamation for food' after the foundation of the People's Republic of China in 1949. The area of cropland increased to 130 000 ha in 1960, and since then some cropland was abandoned due to unsuitability. Since 1999, grassland has being increased under the policy of 'conversion of cultivated land to grassland or forest' for environmental restoration. During the period from 2000 to 2006, about 24 320 ha croplands were converted to grassland or shrubland in Lake Qinghai watershed.

The mix of driving forces of land-use change varies in time and space, across scales. Biophysical drivers may be as important as human drivers (Lambin and Geist, 2001). Cui *et al*. (2006) simulated the impact of land use changes

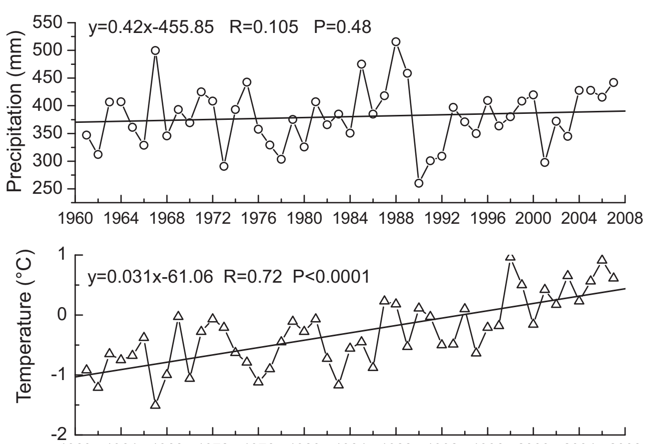

Figure 7. Change of annual precipitation and temperature between 1961 and 2007 at Gangcha meteorological station 10 km northwards to Lake Qinghai.

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on the Tibetan Plateau on local and global climate and concluded that human-induced land use changes on the Tibetan Plateau have had a significant impact on local to regional, and to a lesser extent global, climate. Therefore Lake Qinghai may be an ideal place to track the signal of climate change due to LUCC. The complex mechanism of interaction between climate, LUCC and environment need further deep investigation in this region.

CONCLUSIONS

LUCC analysis indicated that magnitude of the LUCC in Lake Qinghai watershed was generally low; the percentage of the change of various land types relative to the total area was less than 1 per cent. However, lands used for ecological purpose showed a decreasing trend, but lands for crop production and residence showed an increasing trend, suggesting that anthropogenic influence on LUCC had being increasing during the recent decades. Grassland degradation is worthy of note, although small changes in the area of grassland, the productivity was substantially reduced. Grassland degradation was mainly resulted from anthropogenic factors (increasing population, grazing and policy), but lake level decline and area shrinkage was mainly attributed to climate change.

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