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Dynamics of Land Use and Land Cover Changes in An Arid Piedmont Plain in the Middle Reaches of the Kaxgar River Basin, Xinjiang, China

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Abstract: The Kaxgar River Basin, a key section of the Tarim River Basin, is a typical ecologically fragile region that has undergone rapid changes to its spatial patterns over the preceding few decades. In particular, the expansion of salinized land has posed a severe threat to ecological restoration and economic development. This study monitored the rates and patterns of land use and land cover (LULC) changes in the plain area of Aketao County in the middle reaches of the Kaxgar River Basin. Five Landsat images (captured in 1990, 1998, 2002, 2013, and 2018) were divided into seven LULC types: built-up land, cultivated land, woodland and grassland, light-moderate salinized land, heavy salinized land, water areas, and bare land. Subsequently, their dynamic processes were analyzed. The results revealed that in 1990, the dominant LULCs were cultivated land, woodland and grassland, and bare land. Throughout the study period (from 1990 to 2018), the coverage of built-up land, cultivated land, bare land, water areas, and light-moderate salinized land increased; by contrast, that of the other LULC types decreased. The most marked LULC changes were the expansion of light-moderate salinized land (by 6.2% of the study area) and the shrinkage of woodland and grassland (by 9.4% of the study area). Almost all the analyzed LULC types underwent conversion to other types; such conversion occurred most frequently between 1998 and 2018. The conversions of woodland and grassland into cultivated land and light-moderate salinized land were the most notable phenomena. Another highly evident change was the conversion of heavy salinized land into bare land. These results revealed that the expansion of salinized land and the shrinkage of woodland and grassland in the study area were the most severe environmental changes. Therefore, ecological protection and salinization control are urgently required to enable local economic development while not exceeding the environmental carrying capacity and ensuring the safety of the "green corridor" in the lower reaches of the Kaxgar River Basin.

Keywords: Kaxgar River Basin; LULC; remote sensing; GIS

1. Introduction

The term land use and land cover (LULC) refers to an interface between natural systems and human systems; the dynamics of this interface are the primary factor influencing environmental change both globally and locally [1–3]. In recent decades, the land surface has undergone complex and profound changes because of human activity and climate change [4]. The short-term effects of human behavior on the natural environment driven by multiple interacting factors—including demographic, social, economic, political, technological, and institutional variables—are fairly evident [5–7]. According to some studies, the extent and pace of land surface alterations due to human activity have increased rapidly over the preceding three centuries, particularly in the most recent 30 years [8–10]. Worldwide, changes in LULC have affected the natural environment by influencing regional climates, soil quality, biodiversity, hydrology, and the carbon cycle [3,11–14].

Approximately 8×10^6 people live in the basin of the Tarim River, China's longest inland river [15], both arithmetic and physiological population density of this region were eight people and 606 people per square kilometers, respectively [16]. The river runs through two of the country's largest deserts, namely the Taklamakan Desert and Kuluke Desert, both of which are typically arid regions in Western China [17,18]. Over the preceding few decades, the Tarim River Basin have undergone considerable change in terms of LULC. The labor movement could reflect the process of the modified land. A previous study shows that China's western population movement is relatively stable, namely, the amounts of population outflows and inflows are basically equivalent [19]. The people living in Tarim River Basin not only contributed to local economic development, but also caused the ecological degradation [15,20,21]. Labor transfer will gradually increase with the starting of the bullet train services in Xinjiang in 2014. Furthermore, salinized land, a common form of land cover in the middle and upper reaches (from Xiaojiake to Qiala), has also undergone rapid dynamic changes since 1989 [22,23]. However, although the trends and processes of LULC changes are fairly consistent in various parts of the Tarim River Basin, the extent and pace of such changes are inconsistent [22,24,25]. For example, LULC in Xayar County in the middle reaches of the Tarim River Basin changed rapidly between 1989 and 1999 [21], whereas the extent of LULC change in the lower reaches of the basin between 1988 and 2000 was minor, occurring in only 0.355% of the analyzed area [15]. Therefore, research on LULC on a small spatial scale is crucial for the development of reasonable strategies for environmental protection and the utilization of regional land resources.

The Kaxgar River Basin, located at the western edge of the Tarim River Basin, was a headwater of the Tarim River before 1950s [26,27]. Alongside the exploitation and irresponsible utilization of water resources by humans, a reduction in river flow led to the loss of a hydraulic connection between the Kaxgar River and Tarim River. Moreover, the overexploitation of natural resources in the upper reaches of Tarim river basin led to not only the deterioration of the local eco-environment but also the disappearance of the so-called "green corridor" in the lower reaches [24]. Therefore, the processes, trends, and causes of LULC changes must be identified for the formulation of sustainable economic and ecological programs.

The plain area of Aketao County, situated in the middle reaches of Kaxgar River Basin, has undergone severe land salinization processes because of insufficient precipitation, high evaporation, and damaging agricultural irrigation practices [28,29]; consequently, salinized land now covers approximately 35.6% of all cultivated land in the county [30], so the protection of cultivated land is essential for the minimum standard of living of the local people. We discovered that expansion of built-up land into agricultural land was very obvious with the overview from current Google Earth. This paper took the area as a typical region and carried out research on the rates and patterns of LULC change. The study objectives were as follows: (1) to monitor and analyze the rates and extent of LULC change in the plain area of the Kaxgar River Basin and (2) to characterize the trends and degrees of conversion for multiple LULC types. Moreover, we explored the impact of several driving factors (including policy, human factors, and natural forces) on LULC changes in the study area for providing references for decision-making with respect to sustainable eco-environmental and economic development in arid inland river basins.

2. Material and Methods

2.1. Location

The present study area is situated in the northeastern part of Aketao County, Xinjiang Uygur Autonomous Region (XJUAR). On the basin scale, it's located in the Kagxar River Basin which is one of sub-basins of Tarim River Basin. Specifically, the area lies between 39.30°–39.98° N latitude and 75.72°–76.15° E longitude and covers approximately 74,754.8 ha (Figure 1), population density is 210 people per square kilometers. Its altitude ranges between 1266 and 1600 m above sea level. Accounting for only 3.04% of the total land area of Aketao County, the study area is characterized by its alluvial–proluvial plain. Kushan River, which originates from the northeastern slope of the mountain Kongur Tagh, one of the Pamir Mountains, is the main river in this region; it flows from south to north through Aketao County and is eventually utilized for agricultural irrigation. Although the study area accounts for only a small part of Aketao County, industrial production and oasis agriculture in the county are primarily concentrated in this area. Furthermore, the study area is located in mid-latitude Eurasia and therefore features a warm to temperate continental arid climate. The average annual precipitation in this area is 75.5 mm, and rainfall mostly occurs in spring and summer; evaporation can reach as high as 1400 mm [30]. The highest average seasonal temperature occurs in summer and is 23.45 °C, and the lowest average seasonal temperature occurs in winter and is −4.05 °C; the mean annual temperature is 11.01 °C. The main soil types are anthropogenic-alluvial soil, solonchak, meadow soil, and fluvo-aquic soil [31]. The dominant vegetation types are reed, camelthorn, tamarisk, herbs, and Xinjiang Poplar. In recent years, eco-environmental problems such as ecological deterioration and soil degradation (including soil salinization and desertification) have become increasingly severe because of climate change and the adverse effects of human activity. These problems now threaten the sustainable development of the regional (the plain of Aketao County, even the lower reaches of the Kaxgar River Basin) economy and ecological environment.

2.2. LULC Classification and Accuracy Assessment

This study employed satellite data (Landsat images) to analyze patterns of LULC changes from 1990 to 2018. Satellite images (from 1990, 1998, 2002, 2013, and 2018) were obtained from usgs.gov. Four time intervals (1990–1998, 1998–2002, 2002–2013, and 2013–2018) were defined on the basis of the time series of remote-sensing data.

Before classification, we preprocessed remote-sensing images through geometric rectification, atmospheric correction, radiometric calibration, and the transformation of color composites in RGB (Red, Green and Blue) by using ENVI 5.1 software (https://www.harrisgeospatial.com/Software-Technology/ENVI-working). All the classified images had the same spatial resolution (30 × 30 m^2). False color grid composite images were used to classify LULC types. First, principal component analysis was conducted to obtain major land parcels to be used for supervised classification. Maximum likelihood classification was applied because it has been proven superior to be to several other land classification methods in terms of ease of application, ease of operation, and performance [21,32]. Second, random ground control points obtained from high-resolution Google Earth images were used to verify LULC classification outputs. Finally, LULC maps for the reference years (1990, 1998, 2002, 2013, and 2018) with a scale of 1:190,000 were plotted, and temporal changes in LULC were determined and analyzed for interpretation. Clearly distinguishing between woodland and grassland in this region based on the remote-sensing data was difficult; thus, these two types of land were grouped together. The following seven LULC classes were defined (see the LULC classes and their descriptions in Table 1): built-up land, cultivated land, woodland and grassland, light-moderate salinized land salinized land, heavy salinized land, water areas, and bare land. Classification accuracy assessments for the resultant LULC layers in the satellite images were conducted by comparing the sample LULC classes of the classified layer and reference layer. The overall accuracy was calculated, and Kappa analysis was conducted to evaluate the degree of classification accuracy for the error matrix [33].

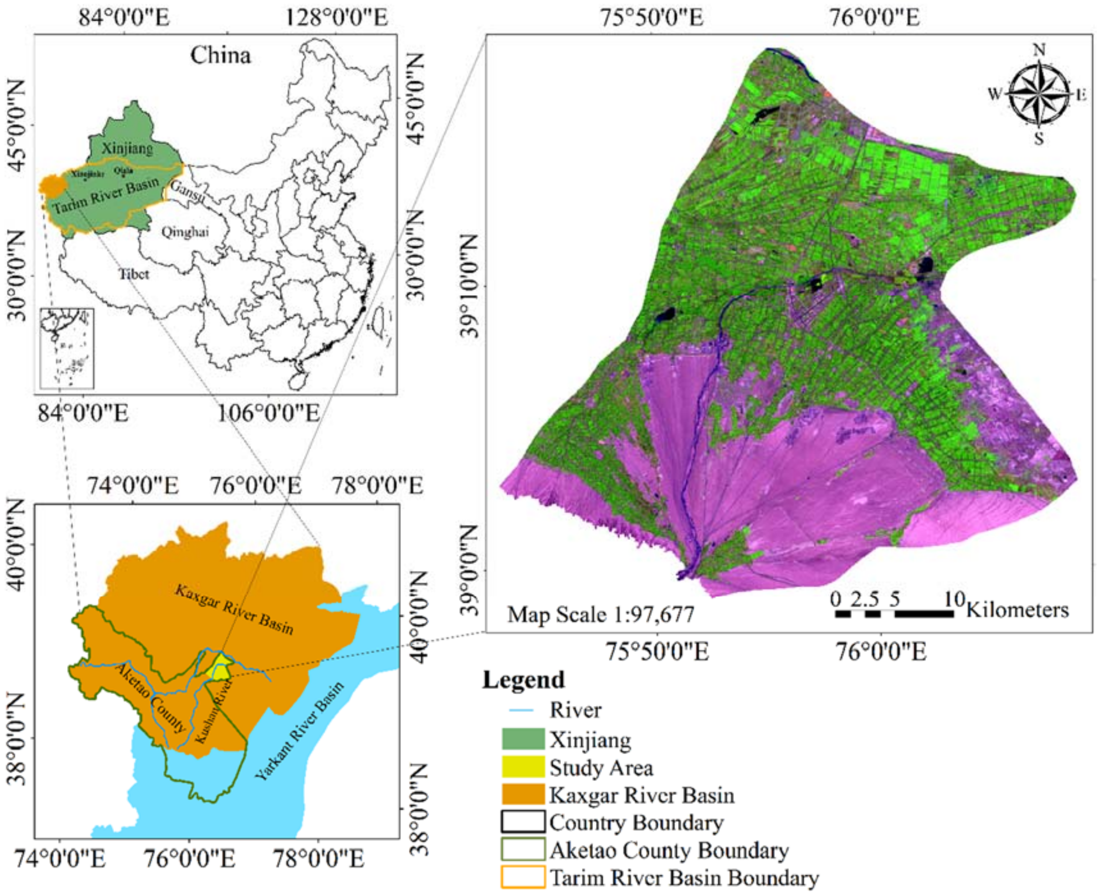

Figure 1. Map of the study area.

Table 1. Description of land use and land cover (LULC) classes used to measure the changes in periods 1990 to 2018.

Code	Land Use/Cover Types	Description
A	Built-up land	Residential areas (emerging rural towns, villages) occupied by living houses including backyard, manufacturing district
B	Cultivated land	Land areas under cropland with visible patterns on satellite imageries
C	Woodland and grassland	Grassland mainly evolved from abandoned agricultural lands, also appeared in low-lying, relatively humid environment at the edge of the oasis. Woodland mainly refers to farmland shelterbelts, orchards and indigenous and landscape trees (growing around the urban and rural settlements)
D	Heavy salinized land	The land serious salinization and at the edge of oasis, surrounded non-cultivated soil salinity is very high and poor environmental conditions
E	Light-moderate salinized land	Distribution terrain relatively flat, in the lower part of alluvial fan, high soil salinity and poor environmental conditions
F	Bare land	Unused land, barren land, Gobi, sandy land, etc.
G	Water area	River and reservoir

In the present study, the overall accuracy of the classified images was 94%, and Kappa accuracy was 87%. All overall accuracy and Kappa accuracy values were >80%, indicting satisfactory classification performance [34].

2.3. Methods for Analyzing LULC Changes

After classification, all the LULC maps were clipped to a common area by using ArcGIS. The Intersect tool in the ArcGIS Analysis toolbox was used to compute change in the area by cross tabulating pairs of time intervals, namely 1990 and 1998, 1998 and 2002, 2002 and 2013, 2013 and 2018, and 1990 and 2018. Transitions between LULC types were evaluated to measure how single areas were employed for multiple forms of land use. Quantified values representing changes between LULC classes were used for statistical analysis to reveal the extent of change to the dynamics of the study area. The degree of change within the same LULC class between two time points was calculated as a percentage, as follows [32]:

$$Net\ change\ in\ area\ (\%) = \frac{(A_{tn} - A_{tn-i})}{A_{tn-i}}100 \quad (1)$$

where A_{tn} is the area of a specific LULC class at time tn, A_{tn-i} is the area of the same class at time $tn - i$, and net change in area (NC) is the percentage change in the area of a specific class between times tn and $tn - i$.

The rate of change within the same LULC class between two time points was calculated as follows:

$$Annual\ rate\ of\ Change\ (\%) = \frac{Net\ Change\ in\ area}{tn - tn - i} \quad (2)$$

where $annual\ rate\ of\ change\ (ARC)$ is the average annual rate of change in the area of a specific LULC class between times tn and $tn - i$.

An LULC shift index (LUSHI) was calculated to assess which LULC type contributed the most to the expansion of each LULC class. The LUSHI was calculated using the following equation [32]:

$$LUSHI = \frac{\Delta LC_{a-b}}{Mean\Delta LC} \quad (3)$$

where $LUSHI$ is the land use shift index; ΔLC_{a-b} is the area of LULC class a converted to LULC class b between times 1 and 2; and $Mean\Delta LC$ is the mean of the areas of all LULC types converted to LULC type b between times 1 and 2.

Notably, the LULC types that contributed the most to the expansion of LULC class had LUSHI values of >1, whereas all the other types had LUSHI values of <1.

The conversion rate within the same LULC class between two time points was calculated as follows:

$$Conversion\ rate\ (\%) = \frac{\Delta LC_{tn-tn-i}}{LC_{tn-i}}100 \quad (4)$$

where $conversion\ rate\ (\%)$ is the conversion rate in the area of a specific LULC class between times tn and $tn - i$, $\Delta LC_{tn-tn-i}$ is the area of conversion for a specific LULC class between times $tn - i$ and tn, and LC_{tn-i} is the area of a specific LULC class at time $tn - i$.

3. Results

3.1. Analysis of LULC Change

The landscape of the study area, especially cultivated land and woodland and grassland, underwent marked change throughout the study period and has become increasingly fragmented over the preceding three decades (Tables 2 and 3; Figures 2 and 3). In 1990, the dominant LULC type was cultivated land, which covered 31.6% of the total study area (74,754.8 ha). The area of cultivated land appeared to shrink from 1990 to 2002, whereas that of bare land exhibited a trend of expansion during the same period. Therefore, bare land became the dominant land use type (covering at least 36% of total area) between 2002 and 2013 (Table 2; Figure 2). Subsequently, the area of cultivated land increased between 2013 and 2018; thus, cultivated land became the main land use type once again. The areas of cultivated land and bare land respectively expanded by 1.1% and 4% of the total study area throughout the study period (Table 2).

Table 2. Area of LULC classes for the periods in 1990, 1998, 2002, 2013 and 2018 in plain area of Aketao County, China.

Land Use/Cover	1990		1998		2002		2013		2018	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Built-up land	196.9	0.3	275.1	0.4	339.8	0.5	698.3	0.9	1353.3	1.8
Cultivated land	23,605.5	31.6	21,840.4	29.2	21,021.4	28.1	23,886.8	32.0	24,463.5	32.7
Woodland and grassland	18,457.3	24.7	11,747.7	15.7	11,486.3	15.4	11,253.5	15.1	11,419.4	15.3
Heavy salinized land	7540.8	10.1	5475.4	7.3	5324.0	7.1	7142.9	9.6	4762.9	6.4
Light-moderate salinized land	3486.8	4.7	7496.2	10.0	8650.4	11.6	8440.7	11.3	8132.5	10.9
Bare land	21135.8	28.3	27,518.4	36.8	27,396.0	36.6	23,006.3	30.8	24,178.6	32.3
Water area	331.6	0.4	401.7	0.5	536.8	0.7	326.4	0.4	444.6	0.6
Total	74,754.8	100.0	74,754.8	100.0	74,754.8	100.0	74,754.8	100.0	74,754.8	100.0

Table 3. LULC changes for the periods 1990–1998, 1998–2002, 2002–2013, 2013–2018 in plain area of Aketao County, China.

Land Use and Land Cover	Reference Year (1990)		Reference Year (1998)		Reference Year (2002)		Reference Year (2013)		Reference Year (1990)	
	1990–1998		1998–2002		2002–2013		2013–2018		1990–2018	
	Net Change in Area (NC, %)	Annual Rate of Change (ARC, %)	NC (%)	ARC (%)	NC (%)	ARC (%)	NC (%)	ARC (%)	NC (%)	ARC (%)
Built-up land (BUL)	39.7	5.0	23.5	5.9	105.5	9.6	93.8	18.8	587.4	21.0
Cultivated land (CL)	−7.5	−0.9	−3.7	−0.9	13.6	1.2	2.4	0.5	3.6	0.1
Woodland and grassland (WLGL)	−36.4	−4.5	−2.2	−0.6	-2.0	−0.2	1.5	0.3	−38.1	−1.4
Heavy salinized land (HSL)	−27.4	−3.4	−2.8	−0.7	34.2	3.1	−33.3	−6.7	−36.8	−1.3
Light-moderate salinized land (LMSL)	115.0	14.4	15.4	3.8	−2.4	−0.2	−3.7	−0.7	133.2	4.8
Bare land (BL)	30.2	3.8	−0.4	−0.1	−16.0	−1.5	5.1	1.0	14.4	0.5
Water area (WA)	21.1	2.6	33.6	8.4	−39.2	−3.6	36.2	7.2	34.1	1.2

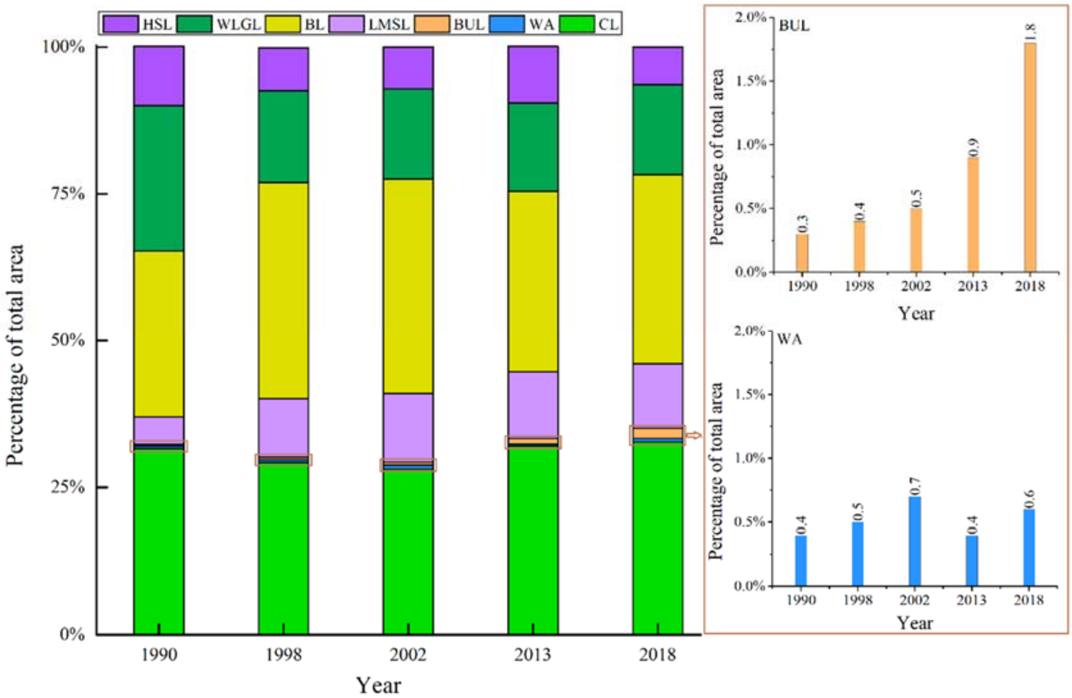

Figure 2. Trend in LULC change in the arid piedmont plain, Aketao County, China (1990–2018).

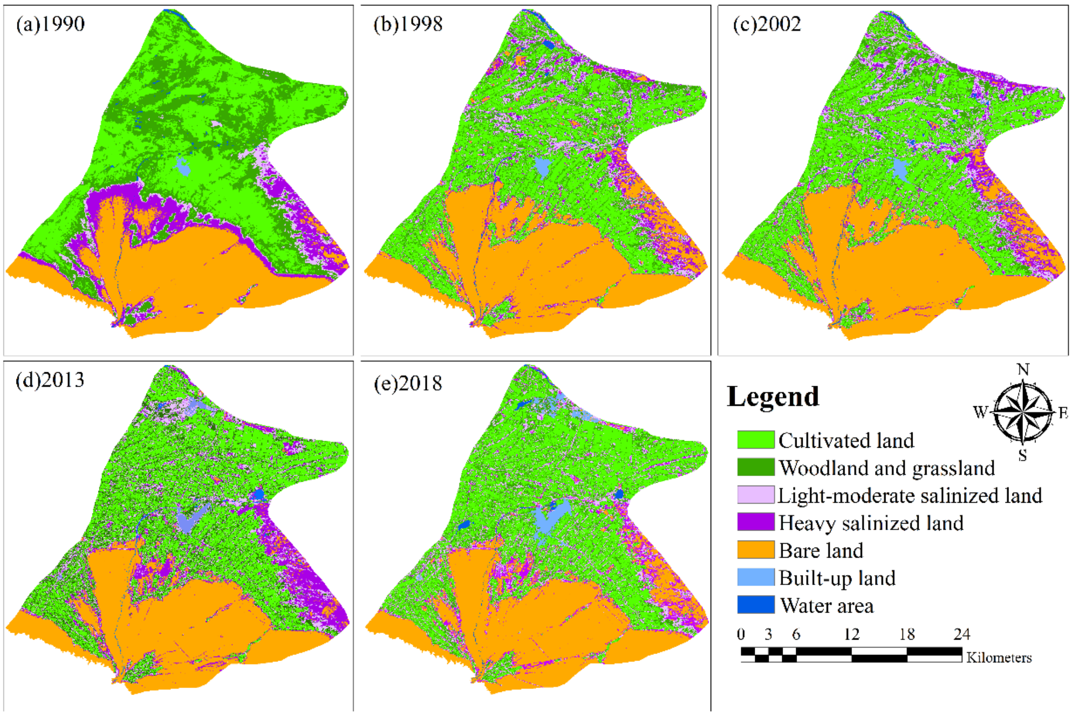

Figure 3. LULC Dynamics (1990–2018) in the arid piedmont plain, Aketao County, China.

Woodland and grassland was another prevalent land cover type, accounting for 24.7% (18,457.3 ha) of the total study area in 1990 and therefore ranking third in area after cultivated land and bare land. However, analysis of the four time intervals revealed a continuous decline in the area of woodland and grassland. This decline was severe between 1990 and 1998; by 1998, woodland and grassland accounted for only 9% of the total study area. Salinized land (including heavy salinized land and light-moderate salinized land salinized land) accounted for 14.8% (11,027.6 ha) of the total study area in 1990 before increasing markedly to cover 20.9% (15,583.6 ha) in 2013; subsequently, the area of such land reduced to 17.3% (12,895.4 ha) by 2018 (Table 2). Although the combined area of built-up land and water areas was extremely small at each time interval, increasing trends were found for both types of land. Furthermore, cultivated land expanded markedly from 1990 to 2018 (Table 2). The area of light-moderate salinized land and that of woodland and grassland exhibited the largest increase and decrease during the study period, respectively.

From 1990 to 2018, the areas of built-up land, light-moderate salinized land, cultivated land, bare land, and water areas increased by 587.4%, 133.2%, 3.6%, 14.4%, and 34.1%, respectively, whereas those of woodland and grassland and heavy salinized land declined by 38.1% and 36.8%, respectively. Light-moderate salinized land and water areas exhibited the most marked changes in area throughout the study period. After 2002, built-up land was the only land use type that underwent marked expansion (Table 3).

Vastly variable rates and trends of change were determined for the LULC types analyzed in this study, and these differences were reflected by the time intervals. Before 2002, built-up land expanded slowly at rates of 5.0% (1990–1998) and 5.9% (1998–2002) per annum. However, subsequently, accelerated expansion at rates of 9.6% and 18.8% per annum occurred in 2002–2013 and 2013–2018, respectively (Table 3). Of all the LULC types, built-up land was the only one that increased steadily throughout the study period. Over the almost three analyzed decades, the area of built-up land increased by 587.4% at a rate of 21.0% (41.3 ha) per annum (Table 3).

Cultivated land, the most prevalent land use type, exhibited rapid expansion from 2002 to 2013 at a rate of 1.2% per annum. By contrast, a much slower rate of expansion, namely 0.5% per annum, occurred between 2013 and 2018. In contrast to the years after 2002, cultivated land decreased steadily at a rate of 0.9% per annum in 1990–1998 and 1998–2002. Woodland and grassland area, the third most prevalent land cover type, exhibited first a rapid rate of decline, namely 4.5% (1990–1998) per annum, and then slower rates, namely 0.6% (1998–2002) and 0.2% (2002–2013) per annum. Subsequently, the area of this type increased slowly from 2013 to 2018 at a rate of 0.3% per annum. Contrasting trends were observed for heavy salinized land and light-moderate salinized land in the same periods, except for 2013–2018. Specifically, the areas of these two types respectively decreased at rates of 6.7% and 0.7% per annum in 2013–2018. In addition, the area of light-moderate salinized land increased at rates of 14.4%, 3.8%, and 4.8% per annum in 1990–1998, 1998–2002, and 2013–2018, respectively, whereas that of heavy salinized land decreased at rates of 3.4%, 0.7%, and 1.3% in the same periods (Tables 2 and 3; Figures 2 and 3).

Bare land, which was mainly distributed in the upper part of the alluvial fan in the piedmont (Figure 3), was the second most prevalent LULC type, covering 28.3% (21,135.8 ha) of the total study area in 1990. Its area then expanded rapidly at a rate of 3.8% per annum between 1990 and 1998 and covered 27,518.4 ha (36.8%) of the total study area in 1998, thereby exceeding the areas of all other LULC types in that year. The area of water areas, which covered only 0.4% of the total study area (331.6 ha) in 1990, increased by 34.1% throughout the study period, thereby exhibiting expansion in all three time intervals, except for a decline in 2002–2013 (Tables 2 and 3).

3.2. *Analysis of Transitions Between LULC Types*

Transitions between LULC types occurred in two forms, namely internal conversion (that of the same LULC type between time intervals) and external conversion (that of different LULC types between different LULC types). Before 2013, the conversion of built-up land into cultivated land was considerable (conversion index > 1.5); in addition, built-up land gradually expanded into woodland and grassland and light-moderate salinized land (conversion indices >1.0) after 1998 (Figure 4). These changes served as a signal that cultivated land required protection. In all three time intervals, the conversion of woodland and grassland into cultivated land was considerable (conversion indices > 3.1). Moreover, some light-moderate salinized land was converted into cultivated land after 1998. Because of the existence of derelict land and its decline in fertility, cultivated land gradually converted into woodland and grassland. In all three time intervals, considerable heavy salinized land converted into bare land, and its average conversion index was over 4.1. The conversion of cultivated land into woodland and grassland was also substantial (average conversion index > 3.8) (Figure 4).

A considerable amount of heavy salinized land was observed on bare land and at the edges of water areas and oases; the conversion index for bare land to heavy salinized land remained over 1.7 after 1998. Moreover, the degradation of woodland and grassland gave rise to an opportunity for the expansion of heavy salinized land. Light-moderate salinized land was a key land use type for the expansion of heavy salinized land in 1990–1998, 1998–2002, and 2013–2018 (Figure 4). In agriculture, inappropriate irrigation practices can cause soil salinization. In the present study area, most woodland and grassland was converted into light-moderate salinized land throughout the study period; the corresponding conversion index remained over 2.4 between 1990 and 2018. The least favorable outcome with respect to heavy salinized land was that such land gradually became bare land. Notably, a considerable amount of heavy salinized land contributed enormously to the expansion of bare land throughout the study period; the corresponding conversion index was over 3.0 (Figure 4). Furthermore, the shrinkage of water areas caused an increase in the area of bare land. The dynamic changes in water areas were mainly caused by climate change and human activity.

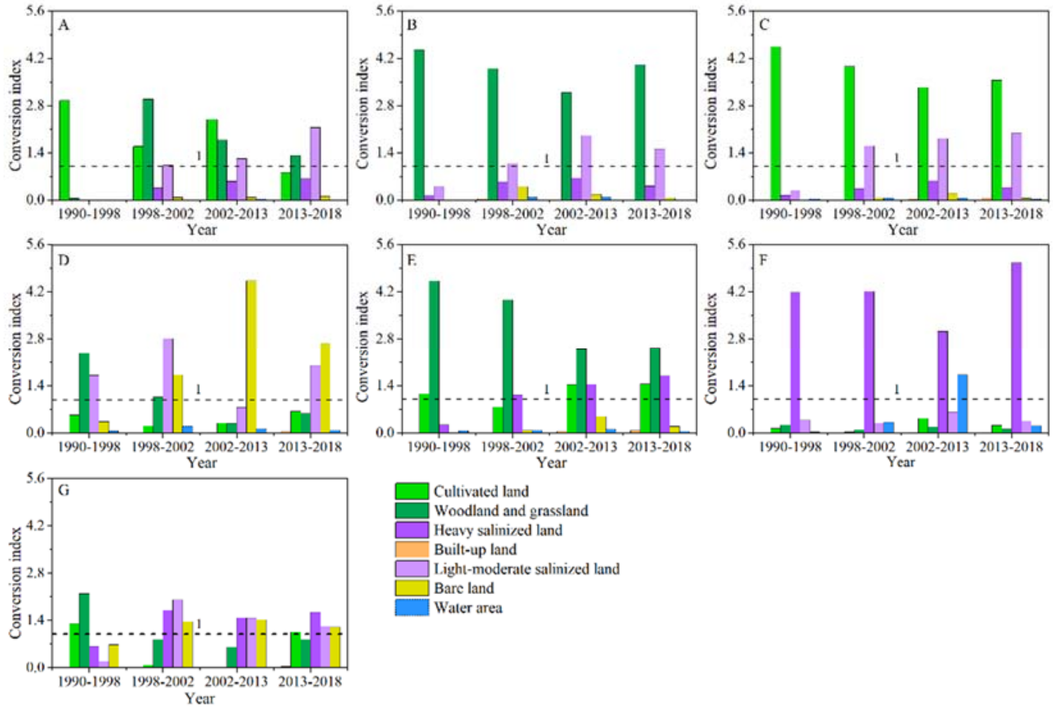

Figure 4. Shift index among different LULC types in the periods 1990-1998, 1998-2002, 2002-2013 and 2013-2018. (**A**–**G**) represent the shift indexes of the specific LULC types to BUL, CL, WLGL, HSL, LMSL, BL and WA, respectively.

Evidently, except for conversion between different LULC types, that of the same LULC type between time intervals was the most prevalent pattern with respect to dynamic landscape processes; the corresponding conversion rate may reflect landscape stability. The internal conversion rates of bare land, cultivated land, and built-up land were all higher than 70%, whereas those of heavy salinized land, light-moderate salinized land, water areas, and woodland and grassland were all lower than 41% (Figure 5).

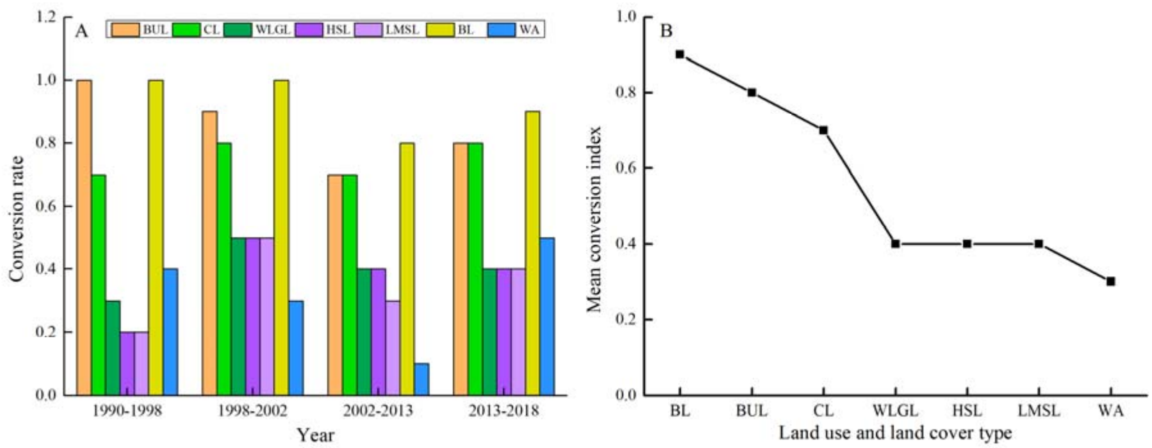

Figure 5. Conversion rate (**A**) and average conversion rate **(B)** of the same LULC type in four time intervals (1990–1998, 1998–2002, 2002–2013 and 2013–2018) in plain area of Aketao County, China.

4. Discussion

4.1. LULC Dynamics (1990–2018)

The expansion of built-up land into cultivated land, woodland and grassland, and light-moderate salinized land is a universal phenomenon in XJUAR [35–37]. In this study, we found that both built-up land and population exhibited increasing trends throughout the study period (Figures 2 and 6). This observation implied a demand among local people for living conditions that meet a certain standard. Furthermore, China's entry into the third stage of urbanization development (the market economy system was implemented gradually) in the late 1980s greatly stimulated the expansion of built-up land. The expansion of built-up land into cultivated land between 1990 and 2002 resulted in a decrease in the area of built-up land and consequential eco-environmental problems. For example, to compensate for the loss of cultivated land, woodland and grassland were reclaimed and converted into cultivated land. The most crucial driver of the expansion of built-up land was the national economic strategy named "China's Western Development," which was implemented in 2000. Based on statistical data from the website of Aketao County government, we discovered that construction investment in 2018 was more than six times compared with that in 2010. The level of investment in infrastructure construction increased; thus, cities gradually expanded in size, thereby posing a severe threat to woodland and grassland [35].

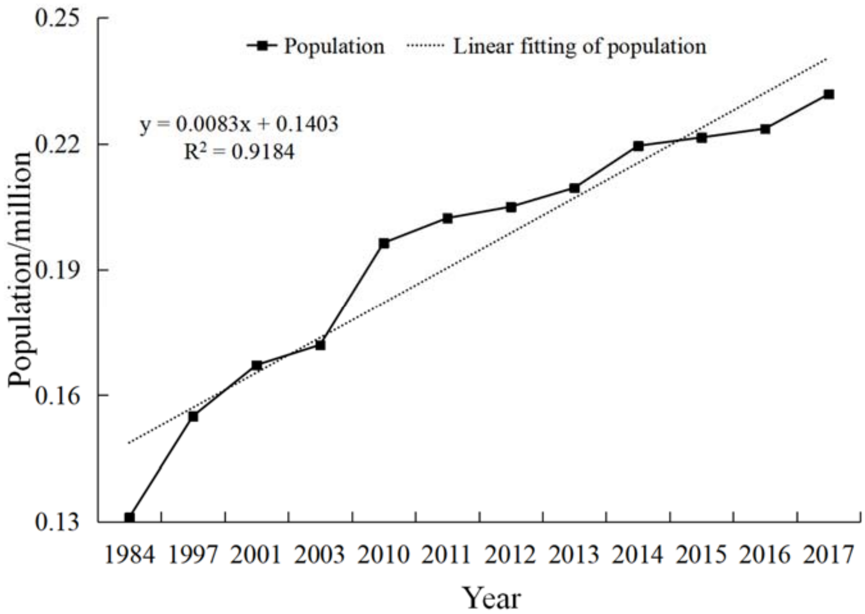

Figure 6. Population dynamic of Aketao county, China in 1984–2017. Note: The data was collected from statistics bureau of Aketao County.

The area of arable land per capita in the study area was extremely small and only 0.16 ha per person in 2018, but it increased 0.02 ha per person compared with that of Aketao County [38]. Therefore, the expansion of cultivated land into woodland and grassland throughout the study period was the main economic driver during this period because of the dwindling supply of arable land per capita due to population growth (Figure 6). Most heavy salinized land was found on the edges of oases, and the area of such land shrank continuously between 1990 and 2002. This shrinkage had two possible causes, namely large-scale conversion of heavy salinized land to bare land and the decline of the annual evaporation capacity (Figures 5 and 7). In view of severe soil salinization in Aketao county, local government according to "National Land Improvement Planning 2011-2015" positively explored the methods of inhibition and improvement of soil salinization by providing land improvement projects (see website of Akeotao County government). This measure limited soil salinization to some extent, and the area of heavy salinized land declined between 2013 and 2018. Notably, although this area exhibited a decreasing trend throughout the study period, some land cover types (woodland and grassland, light-moderate salinized land, and bare land) were still converted into heavy salinized land.

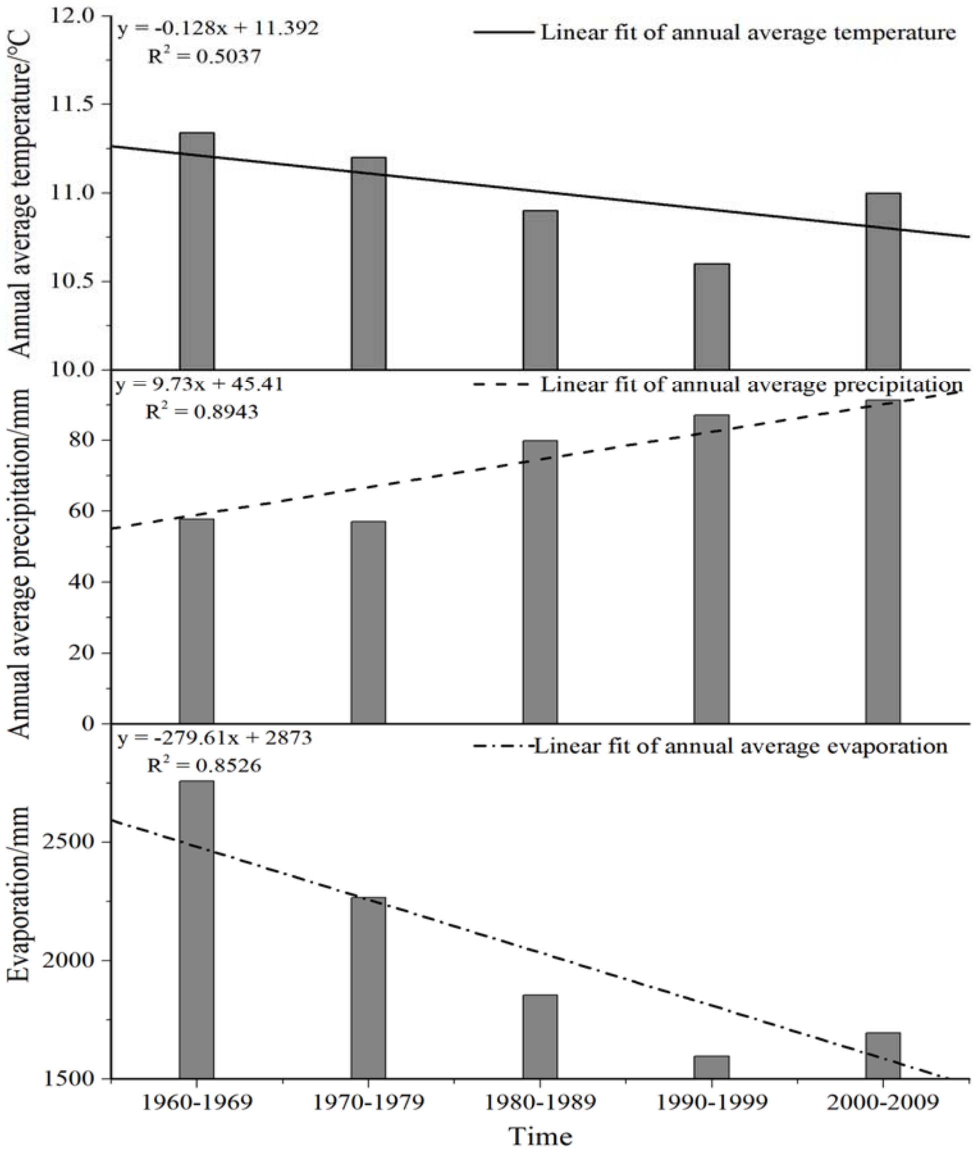

Figure 7. Climate (temperature, precipitation and evaporation) change of Aketao County, China in 1960–2009. Note: The data was collected from Meteorological Bureau of Aketao County.

As mentioned, water sources were the main factor restricting oasis development in the arid region. Specifically, where a water resource is present, so is an oasis. However, water source can induce the production of salinized land in areas with low rainfall and high evaporation. Therefore, in this study, the edges of the area in which woodland and grassland grew usually appeared light-moderate salinized land [30]. Evidently, unsuitable irrigation practices often led to the conversion of farmland into salinized land (Figure 8). In the study area, precipitation exhibited an increasing trend, with a rate of increase of 9.7 mm per decade since the 1960s. Moreover, runoff from Kushan River exhibited an increasing trend alongside an increase in meltwater from glaciers [39]. These trends may have led to the expansion of the water table, which in turn may have facilitated the enhancement of actual evaporation and been conducive to soil salinization (Figure 8).

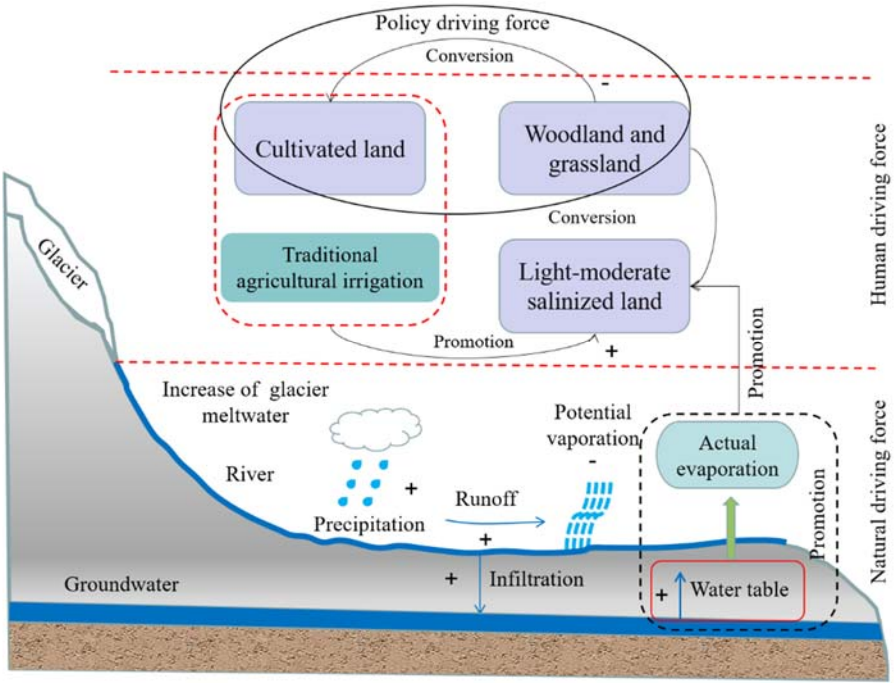

Figure 8. Schematic diagram of causes leading to the expansion of light-moderate salinized land and the shrinkage of woodland and grassland in plain area of Aketao County, China. Note: +, − represent the increase and decrease, respectively.

4.2. Conversion Between LULC Types

Analyses of the present results revealed that almost all the analyzed LULC types underwent deep and complex transitions at different times. The most notable phenomenon, namely the expansion of built-up land, was associated with the widespread use of woodland and grassland and cultivated land. This observation was consistent with those of most related studies, which have also found that the expansion of built-up land occurs at the expense of garden land and cultivated land [37,40]. Evidently, lightly salinized land also contributed substantially to the development of built-up land through the implementation of the "fundamental farmland protection regulations" in 1998 (Figure 4A).

Notably, much of the downsizing of cultivated land occurred between 1998 and 2002, possibly because of the policy named "China's Returning Farmland to Forests." The area of woodland and grassland decreased continuously throughout the study period; this decline was especially evident before 1998. Most such land was converted into salinized land and farmland; this conversion reflected not only the deterioration of the eco-environment but also the shortage of arable land per capita due to population growth. In 1990, very little light-moderate salinized land was present in the study area. The gradual increase in the area of such land after 1990 may have been a result of human activity and natural factors such as unsuitable agricultural irrigation practices and the expansion of the water table [28,30]. The scale of bare land, which was mainly distributed in the upper part of the alluvial fan, remained relatively stable. However, salinization in low-lying areas and human activity in oases were the main factors behind the conversion of bare land.

4.3. Driving Factors of LULC Changes

LULC trends observed in the study area revealed marked changes throughout the 29-year study period. Regarding changes in area size, the shrinkage of woodland and grassland and the expansion of light-moderate salinized land were the most extreme changes. Regarding rates of change, built-up land evidently had the fastest rate of all the LULC types. These dynamic process resulted from interactions among driving forces, including human factors, natural forces, and policy.

4.3.1. Human Factors

In the study area, the human factors that induced LULC changes were population growth, agricultural irrigation, economic benefits, and educational background. Based on the statistical data from the website of Aketao County government. In 1984, the population of Aketao County was approximately 0.13 million; most of these people lived in plain areas. By 2017, the population of this county had increased by 76.9% to approximately 0.23 million. Therefore, during these 34 years, the population increased at a rate of 2.26% per annum. This increase led to a decrease in the amount of arable land per capita and subsequently induced the expansion of cultivated land into woodland and grassland. Moreover, many of the people residing in this region have a low education level [41] and lack knowledge of suitable farming practices and eco-environmental protection. Therefore, such people tend to pursue economic benefits at the expense of the ecological environment. For example, the large-scale conversion of woodland and grassland into cultivated land was performed for increasing economic income. Regarding agricultural productivity, although irrigation techniques improved in some villages in the study area throughout the study period, the traditional irrigation model that rapidly induced soil salinization remained widely used.

4.3.2. Natural Forces

The study area is located in mid-latitude Eurasia and has a warm to temperate continental arid climate. The main characteristics of the weather there are low rainfall and high evaporation (Figure 7). Water resources are the most influential factor in terms of shaping landscape patterns. Moreover, high surface evaporation forces saline in the soil to rise to the surface, eventually leading to soil salinization [21]. Alongside global climate change, local precipitation in the study area exhibited an increasing trend between 1960 and 2009, and runoff from Kushan River increased from 1962 to 2002 because of the acceleration of glacier melting [26]. These factors caused the expansion of the water table and further promoted the expansion of salinized land.

4.3.3. Policy

Policies and other governmental measures consistently play a key role in LULC changes. Since 1978, alongside the implementation of China's "Economic Reform and Opening Up" strategy, farmers' enthusiasm for labor greatly increased [42], and rapid agricultural development occurred, leading to the large-scale conversion of woodland and grassland into cultivated land before 1998. The government realized that the deterioration of the ecological environment required an urgent solution and therefore proposed a project called "returning farmland to forestry or pasture" in 1999. As a result, in the late 1990s, farmland with low fertility and severe salinization was gradually replaced by woodland and grassland. According to the news from the website of Aketao County government, so far, the total of 1.2×10^7 ha characteristic fruit has been planted in Tarim Basin under the drive of this strategy. In 2002, the Chinese government launched another economic development strategy called the "Development of the Western Regions of China," which strongly promoted the expansion of built-up land. But this strategy also affected the agricultural development because of the part of cultivated land being occupied by built-up land. In order to protect arable land, government developed a systemic plan which included agricultural compensation and agricultural skills training to motivate the farmers' enthusiasm. So agricultural land increased from 2013 to 2018.

5. Conclusions

Analysis conducted using Landsat data revealed that LULC types in the plain area of Aketao County underwent complex and profound changes during the study period (1990–2018). In 1990, the most prevalent LULC types were cultivated land, woodland and grassland, and bare land, collectively covering 84.6% of the study area. Of these three types, cultivated land was the most dominant. After 1990, bare land and cultivated land alternated as the most dominant LULC type.

By contrast, the area of woodland and grassland declined throughout the study period, particularly between 1990 and 1998. From 1990 to 2018, the areas of cultivated land, bare land, built-up land, water areas, and salinized land (light-moderate salinized land and heavy salinized land) increased, whereas that of woodland and grassland decreased. The expansion of light-moderate salinized land and the shrinkage of woodland and grassland were the most marked LULC changes. The degree and rate of conversion between LULCs in each time interval may have been related to a number of factors, including human factors, natural forces, and policy. The conversion of woodland and grassland into cultivated land was the most prevalent pattern of LULC change, and those of woodland and grassland into light-moderate salinized land and heavy salinized land into bare land were also apparent. In summary, the degradation of woodland and grassland and soil salinization were the most severe eco-environmental problems in the study area during the study period. To prevent this situation from becoming more severe, agricultural irrigation techniques must be improved, and groundwater must be used reasonably to ensure a balance between economic and ecological development.

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