

Article

Analyzing the Process of Land-Use Transfer Flow in the Suhai Lake Basin in China, 1980–2018

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Abstract: The Suhai Lake Basin has held major ecological status as a crucial component of the Qinghai-Tibet Plateau's ecological security barrier. The Suhai Lake Migratory Bird Nature Reserve's safety and the livelihood of Kazakh citizens are now directly endangered by the frequent switching between land-use types and the decrease of ecosystem service functions caused by climate change and human activity. As a result, this work introduces the idea of land-use transfer flow. Through the application of interval level change and the land-use transfer chain, the process, affecting factors, and current issues of land-use change in the Suhai Lake Basin over the past 40 years are thoroughly investigated. The results showed that the intensity of land-use change was significant, at 0.055%, during the period 1990–2000, whereas the grassland area significantly increased, with a net increase of 23.07 km², mainly from the conversion of saline-alkali land, swamp, and other unused land in the middle and lower reaches. The key factor influencing the growth of the grassland throughout this time has been the ecological management policy. As a result of the climate's ongoing warming between 2000 and 2018, glacial meltwater and precipitation increased, the middle and lower ranges of the groundwater table rose, and the grassland degradation, swamp shrinkage, and soil salinization in the watershed all worsened. The degradation of grassland will result from both overgrazing and overprotection. Suhai Lake Wetland and Haizi Grassland Wetland are the most readily apparent examples of land-use changes in the Suhai Lake Basin from a spatial perspective. More consideration should be given to the ecological deterioration and land exposure in the glacier retreat zone of the upstream source region. The results can provide important information on the impact of regional development and the environmental governance policies of the changes in land use/cover in the Suhai Lake Basin.

Keywords: land-use change; temporal and spatial characteristics; driving factors; Suhai Lake Basin



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1. Introduction

The Qinghai-Tibet Plateau, known as the ‘the roof of the world’ has been called the ‘third pole’ of the world. It has a huge influence on regional and global climate through thermal and dynamic action such that it is characterized as ‘the sensitive area’ and ‘the startup region’ in China and ‘the driving force’ and ‘the amplifier’ for global climate change [1]. Global climate change has had significant impacts on the ecosystem and natural resources of the Qinghai-Tibet Plateau, including permafrost degradation, glacier recession, grassland degradation, and lake expansion [2,3]. Coupled with the impact of human activities, the surface landscape and land-use types of the Qinghai-Tibet Plateau have changed. Land-use/cover patterns of the Qinghai-Tibet Plateau are important foundations supporting the structure and function of the plateau ecological barrier. It not only affects the ecological conditions and regional development of the plateau itself but also has great environmental effects on the region and the world [4–6]. As a result, expansive studies on

land-use and land-cover change (LULCC) in the Qinghai-Tibet Plateau have attracted the attention of academics both domestically and internationally [7].

From the perspective of the whole Qinghai-Tibet Plateau, the land-use structure is relatively stable mainly under the influence of climate change and human activities [8–11]. In the context of climate warming, the expansion of grassland and wetland has curbed the trend of land-cover degradation and improved the macroscopic condition of the ecosystem [12,13]. However, the Qinghai-Tibet Plateau occupies a vast territory, with a length of about 2800 km in the east and west, a width of about 300–1500 km in the north and south, and a total area of about 2.5 million square kilometers. There are obvious spatial differences in land-use change and its driving factors [9,14]. The northern Tibetan plateau is an important animal husbandry production base in China. Its main land-cover type is alpine grassland, which was seriously degraded during 1990–2000 owing to unreasonable grazing. However, with the implementation of the grazing prohibition policies, the trend of grassland degradation in the plateau was alleviated during 2000–2015 [15,16]. Among them, as the priority ecological protection area in China, from 1980 to 2015 in the Sanjiangyuan region, the LULCC showed a fluctuating increase in the area of grassland, water, and build-up land; it showed a significant decrease in the area of unused land such as bare land; and the forest land remained basically unchanged [17]. Located in the northeast of Qinghai-Tibet Plateau, the magnitude of land-use change in the Qinghai Lake Basin is generally low, mainly after the year 2000. Under the combined action on climate and human activities, the grassland degenerated and was converted mainly into cultivated land, build-up land, and unused land [18,19]. As the distribution area of cultivated land and build-up land in the Qinghai-Tibet Plateau concentrated, the land use of the Hehuang Valley has changed. The area of forest land, build-up land, and unused land has increased, and the area of cultivated land has reduced because of the implementation of ecological projects such as returning farmland to forest and grassland, and the Western Development Strategy [20]. In the southern Tibetan valley, the Yarlung Zangbo River Basin showed that permanent glacier snow significantly degraded during 1980–2000 because of global warming. After 2000, with the strengthening of human activities and the acceleration of urbanization, the building area increased significantly and the grassland area decreased to a certain extent [21,22]. There is obvious grassland degradation in Lhasa, and a large area of grassland has been transformed into cultivated land. In summary, under different natural conditions and the intensity of human activities, the pattern, process, and influence of LULCC have obvious regional characteristics in the vast Qinghai-Tibet Plateau [23]. Therefore, it is necessary to carry out research on land-use change at different spatial and temporal scales in the Qinghai-Tibet Plateau.

Located in the northeast of the Qinghai-Tibet Plateau, the Suhai Lake Basin is an important part of the ecological security barrier of the Qinghai-Tibet Plateau [24]. It forms a somewhat-isolated ecosystem thanks to the relatively limited basin topography and independent regional water system. The Da Haltang River and the Xiao Haltang River are the main rivers in the Suhai Lake Basin. The Yarlung Zangbo River Basin and the Hehuang Valley have higher levels of land development and use than the Suhai Lake Basin, which is primarily grazed by the livestock of herders, with little interference from other human activity. However, in recent decades, this has changed because of global warming, glacier melting intensification, and unreasonable human-caused grazing behavior, land-use and land-cover change with the prominent ecological and environmental problems, such as soil salinization, swamp atrophy, grassland degradation, glacier retreat, etc. [25–28]. In the future, with the development of the Water Diversion from Haltang to Dang River project, the Da Haltang River, as an important water source for the Dunhuang Oasis, will certainly have a significant impact on the basin hydrological processes and land use/cover. Therefore, an in-depth study of land-use change and its influencing factors in this basin over the past 40 years can predict the ecological problems that may be brought by land-use change in this basin in the future, which not only is important for local ecological

restoration but also can provide theoretical references for the future implementation of the Water Diversion from Haltang to Dang River project.

In this paper, the concept of land-use transfer flow is introduced. By using the methods of interval level change, a land-use transfer matrix, and a land-use transfer chain, the spatial and temporal characteristics and driving factors of land-use change in the Suhai Lake Basin over the past 40 years are analyzed. In addition, the ecological problems in the Suhai Lake Basin are discussed from the perspective of land-use change. The following are the primary research goals: (1) to describe the different types of land use and their spatial distribution in the Suhai Lake Basin; (2) to examine the Suhai Lake Basin's land use's spatial and temporal evolution characteristics; and (3) to identify the driving forces behind land-use change and, using this information, to investigate the ecological and environmental issues in the Suhai Lake Basin in order to offer some recommendations for the ecological preservation and restoration of the basin.

2. Materials and Methods

2.1. Description of the Study Area

The Suhai Lake Basin (93°30′–97°20′ E, 38°00′–39°30′ N) (Figure 1) is on the northern edge of the Qinghai-Tibet Plateau, leaning on the A-erh-chin Mountains and Danghenan Mountains in the north and the Saishiteng Mountains and Saishiteng Mountains in the south. It is an important part of the ecological security barrier of the Qinghai-Tibet Plateau, and its ecological function and status are significant. The Suhai Lake Basin is a closed inland basin occupying 15,730 km², high in the east and low in the west, surrounded by mountains. The basin is characterized by year-round drought and low rainfall, and the temperature difference between day and night is large. The annual average temperature is −4–0 °C, the annual average precipitation is 60–200 mm, and the annual average evaporation is 2100–2400 mm. The mountain runoff of the Da Haltang River and Xiao Haltang River is the main water source for the basin area in the middle and lower reaches, and the Suhai Lake Wetland in the river tail area features the provincial Migratory Bird Nature Reserve. The ecosystem of the basin in arid environments is vulnerable, which is very sensitive to global climate change and human intervention.

The land-use types in the basin include mainly forest land, grassland, water, build-up land, and unused land, of which the area of unused land accounts for 77.52% and the area of grassland accounts for 17.15%. The Kazakhs are the only ethnic minority living in the Suhai Lake Basin, and the disturbance of human activities to the ecosystem is relatively small, mainly grazing.

2.2. Data Sources

2.2.1. Land-Use Data

The land-use data were obtained from the Chinese National Land Cover Database (CNLCD), which was developed by the Chinese Academy of Sciences (CAS) (<http://www.resdc.cn/> accessed on 1 April 2021) [29]. Many previous studies have reported that the overall accuracy was over 95%; specifically, the accuracy was 98% for grassland, forest land, and built-up land and 99% for cropland [30–32]. The data used in this study include five periods of land-use change data (Figure 2): 1980, 1990, 2000, 2010, and 2018 (spatial resolution of 30 m × 30 m). In this study, the land-use types were classified into six primary land-use categories and 15 secondary land-use categories according to the land-use classification standard of the Chinese Academy of Sciences. Because of the uniform glacier development in the mountainous areas of the upper reaches, the end of the river is the Da Suhai Lake Wetland and the Xiao Suhai Lake Wetland, where saline-alkali land and swamp are the main land-use types. According to the actual situation of the study area, the land-use types of the watershed were classified into nine categories: forest land, grassland, glacier/permanent, lakes, other water land, build-up land, saline-alkali land, swamp, and other unused land.

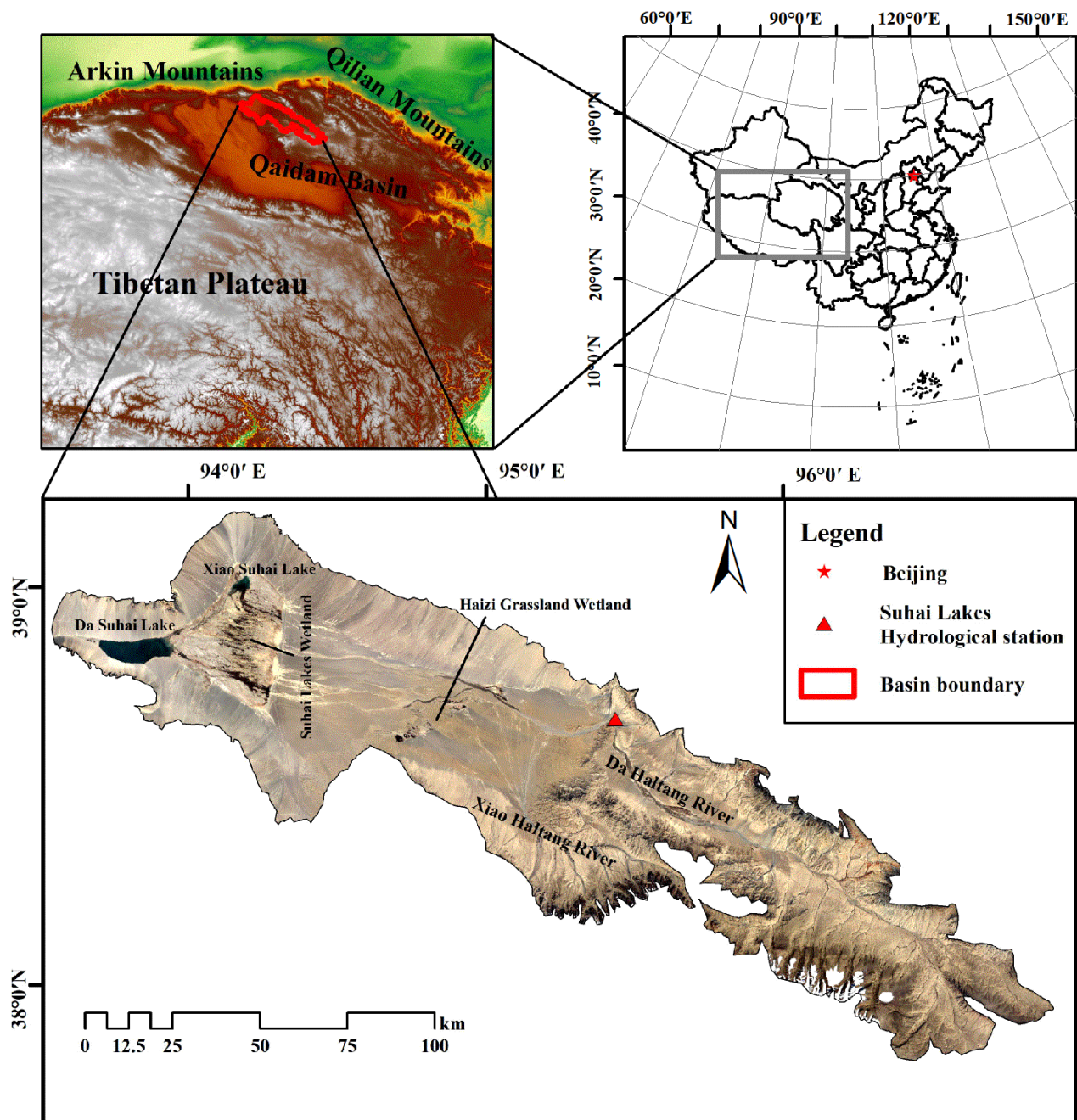


Figure 1. Survey map of the study area.

2.2.2. Meteorological Data

The meteorological data were derived from the National Tibetan Plateau Scientific Data Center (<http://data.tpdc.ac.cn> accessed on 1 April 2021) [33], including the annual scale data of near-surface temperature and precipitation rate from 1979 to 2018. The spatial resolution is $0.1^\circ \times 0.1^\circ$. According to the ArcGIS software used for an interpolation extraction analysis, the near-surface precipitation rate was converted to near-surface annual precipitation by raster calculation, and then the extraction analysis was carried out.

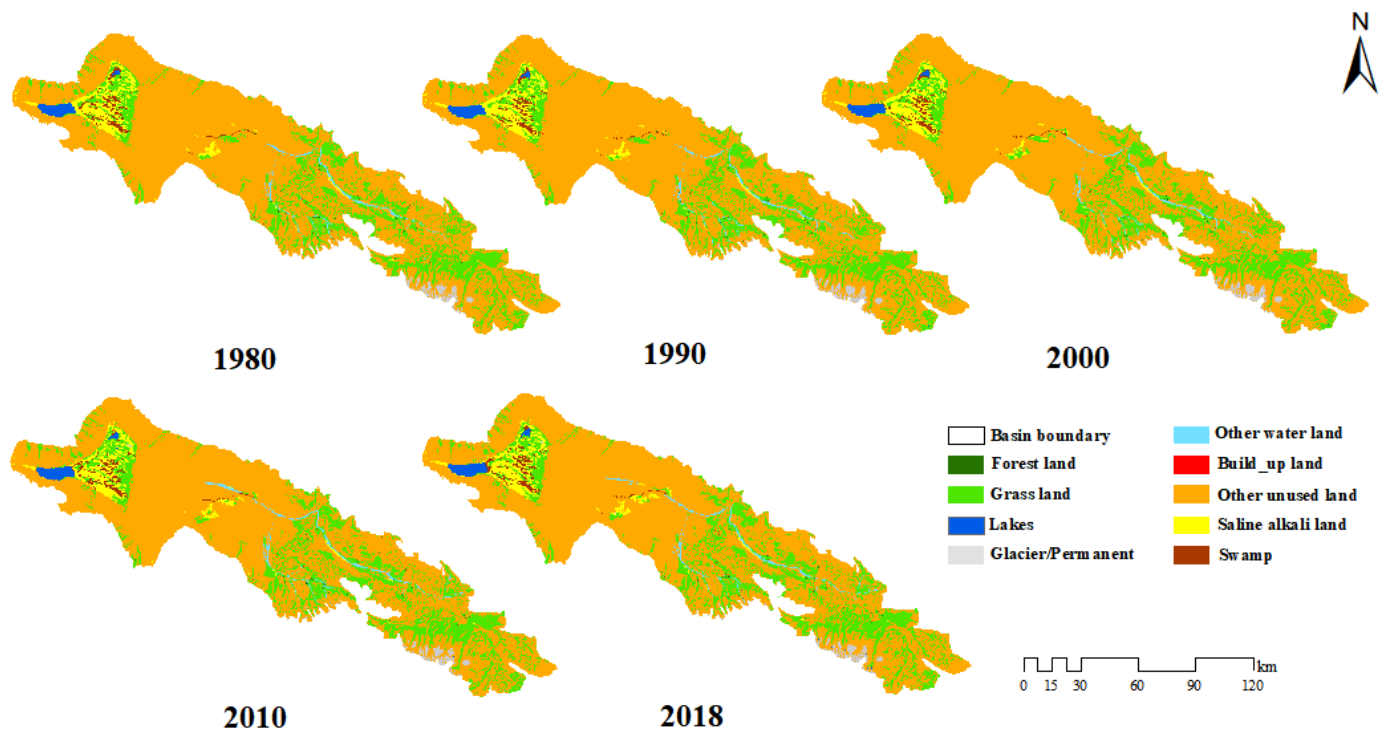


Figure 2. 1980–2018 Land-Use Types in the Suhai Lake Basin.

2.3. Methodology Description

2.3.1. Interval Level Changes

The interval level can quantitatively reflect the intensity of land-use change within a certain time interval. By comparing the intensity of change in a certain period with the average intensity of change in the whole study period, the stability of land-use change can be quantitatively reflected in a certain time interval [34]. The expression is as follows:

$$S_t = \frac{\sum_{j=1}^J \left[\left(\sum_{i=1}^J C_{tij} \right) - C_{tij} \right] / \left[\sum_{j=1}^J \left(\sum_{i=1}^J C_{tij} \right) \right]}{Y_{t+1} - Y_t} \times 100\% \quad (1)$$

$$U = \frac{\sum_{t=1}^{T-1} \sum_{j=1}^J \left[\left(\sum_{i=1}^J C_{tij} - C_{tij} \right) - C_{tij} \right] / \left[\sum_{j=1}^J \left(\sum_{i=1}^J C_{tij} \right) \right]}{Y_T - Y_1} \times 100\% \quad (2)$$

where $Y_{t+1} - Y_t$ is the interval between the beginning and end of the study period; C_{tij} is the number of land classes converted from i to j over time t ; S_t denotes the intensity of land-use change in period t ; and U is the average intensity of land-use change throughout the study period.

2.3.2. Land-Use Transfer Matrix

The land-use transfer matrix can comprehensively and concretely reflect the quantity and structure characteristics of different land-use types in a certain time interval and has rich statistical significance for the change of land-use transfer in different places over the research time interval [35]. The calculation formula is as follows:

$$S_{ij} = \begin{vmatrix} S_{11} & S_{12} & \dots & S_{1n} \\ S_{21} & S_{22} & \dots & S_{2n} \\ \dots & \dots & \dots & \dots \\ S_{m1} & S_{m2} & \dots & S_{mn} \end{vmatrix} \quad (3)$$

where S is the area; m and n are the number of land-use types before and after the transfer, respectively; i and j are the land-use types at the beginning and the end of the study period, respectively; S_{ij} is the area of land use i at the beginning of the study period to land use j at the end of the study period.

2.3.3. Land-Use Transfer Flow

In order to describe the conversion between land use more graphically, we introduce the concept of flow, and land-use transfer flow has both size and direction. Its size represents the area of a certain type of land to another type of land, and the direction refers to the transformation of one land type to another. The conversion from one land class to other land classes is called outflow, and the conversion from other land classes to that land class is called inflow. The sum of inflow and outflow is the land-use transfer flow, and the difference between inflow and outflow is the net value of land-use transfer flow. The calculation formula [36] is as follows:

$$L_f = L_{out} + L_{in} \quad (4)$$

$$L_{nf} = L_{in} - L_{out} \quad (5)$$

where L_f represents the land-use transfer flow; L_{out} represents the outflow; L_{in} represents the inflow; and L_{nf} represents the net value of land-use transfer flow. When the value is positive, it means net inflow; conversely, when the value is negative, it means net outflow.

2.3.4. Land-Use Transfer Chain

The land-use transfer chain refers to the process chain consisting of a process from one land-use type to other land-use types in a certain time series, including unidirectional chain, reciprocating chain, and complex chain [37]. It can intuitively reflect the detailed process of land-use change within a certain time series. Different land-use types are assigned different values, and the specific codes are as follows: forest land-1, grassland-2, lakes-3, glacier/permanent-4, other water land-5, build-up land-6, other unused land-7, saline-alkali land-8, and swamp-9. According to the overlay analysis function of GIS, the land-use conversion codes are obtained in turn. For example, the codes 2288, 2228, and 2888 (abbreviated as 28) are expressed as unidirectional chain from grassland to saline-alkali land. In addition, 2282 and 2882 (abbreviated as 282) are the reciprocating chains indicating that grassland is transformed from grassland to saline-alkali land and then to grassland. Lastly, 2875 is the complex chain that indicates that the grassland has been transformed into saline-alkali land, then into other unused land, and finally into other waters.

3. Results

3.1. Conversion of Land-Use Structures and Types

It was discovered that the other undeveloped land in the basin accounted for the majority and nearly covered the whole basin by comparing the statistical analysis of land-use area changes in the Suhai Lake Basin in 1980, 1990, 2000, and 2018. The second kind is grassland, which is primarily found in the middle and lower reaches and includes the Suhai Lake Wetland and the Haizi Grassland Wetland. When the year 2018 is taken as an example, the other unused land area is 10,043.27 km², accounting for 63.85% of the entire watershed area, and the grassland area is 2659.63 km², accounting for 16.91%. The total proportion of other types of land is only 19.24%.

Forest land and saline-alkali land were primarily transformed into grassland, according to the transfer matrix of various land uses (Figure 3). Swamps were primarily transformed into lakes, whereas lakes were transformed primarily into swamps. The findings show that between 1980 and 1990, there was an increase in grassland area and a mutual conversion of swamp and lakes. From 1990 to 2000, swamps were converted primarily into grasslands, lakes, and saline-alkali land, with the conversion of grasses being comparatively more significant. The most noticeable relative area transfer from saline-alkali

land and marsh land between 2000 and 2010 occurred when they were converted primarily into grassland and a tiny portion into lakes. The largest relative area was still converted into grassland. From 2010 to 2018, other water land had the maximum relative area transferred out, converted mainly into other unused land. However, most land-use types transformed into grassland.

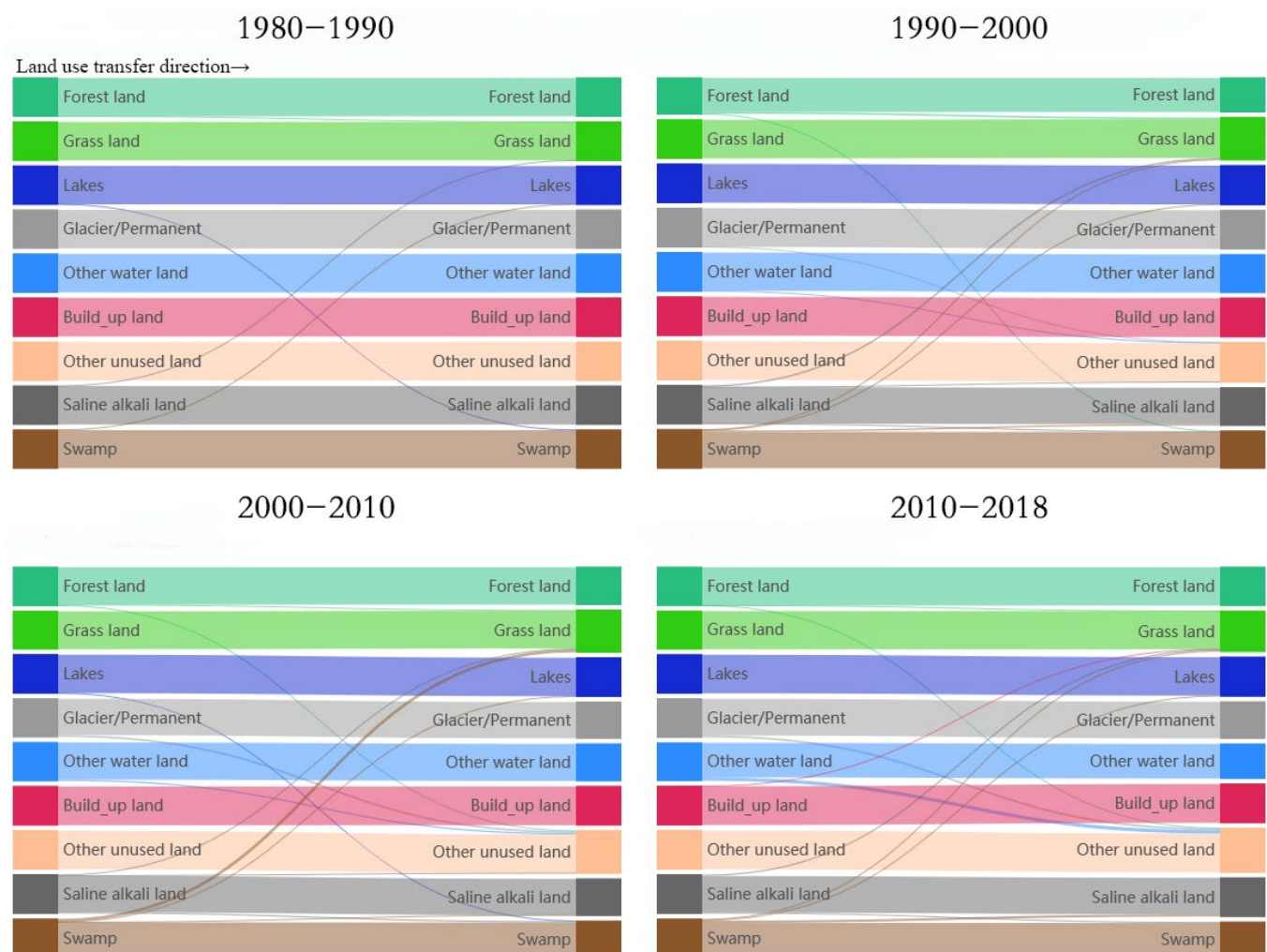


Figure 3. During 1980–2018, the transfer matrix of different land uses.

Figure 4 shows the area of each category as each relates to changes in the area transformed by different land uses between 1980 and 1990. The area of grassland increased by 15.03 km² between 1990 and 2000, whereas the area of other unusable land and saline-alkali land shrank. They saw a 16.44 km² decrease in the amount of saline-alkali land and a 29.14 km² decrease in the area of other unusable land. Smaller areas also expanded in lakes and other watery areas. As saline-alkaline and marsh regions grew between 2000 and 2010, the extent of grassland shrank by 26.83 km². Additionally, the glacial area's retreat caused an increase in lakes and other watery terrain. Between 2010 and 2018, the area of grassland decreased, which was echoed by the increase of saline-alkali and swamp areas.

According to the above analysis, from the perspective of land-type change, the area of grassland increased during 1990–2000, when other land types were transformed into grassland. Meanwhile, the area of grassland decreased during 2000–2018, accompanied by the retreat of glaciers, expansion of lakes, and increase in saline-alkali land area. It can be seen that the ecological environment in this area is gradually deteriorating, and it is urgent to engage in necessary environmental governance.

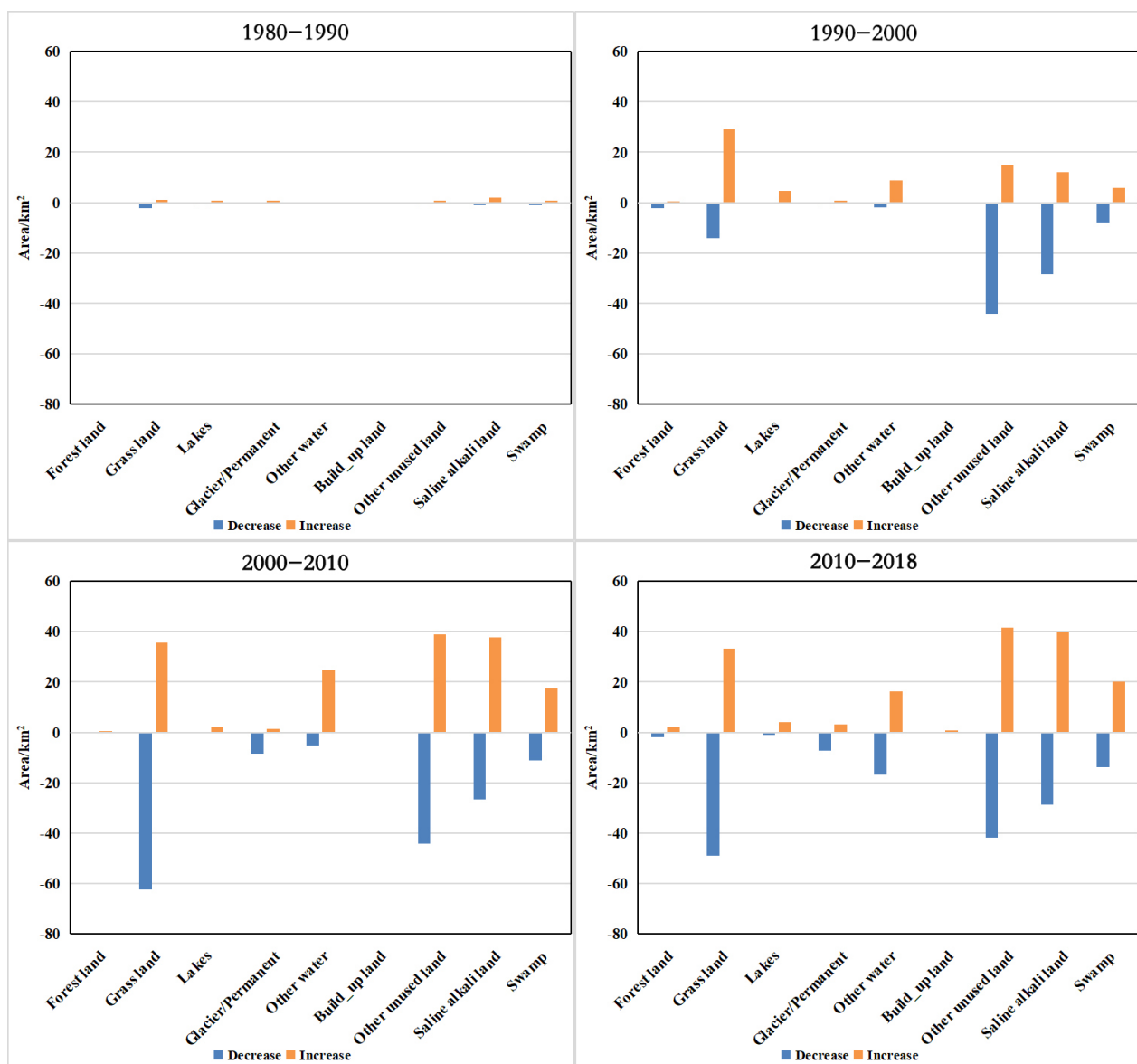


Figure 4. The transfer-in and transfer-out areas of various land-use types from 1980 to 2018 (note: the positive value is the transfer-in area, and the negative value is the transfer-out area).

3.2. Characteristics of Land-Use-Intensity Change

From Figure 5, in the Suhai Lake Basin from 1980 to 2018, the intensity of changes in various land-use types showed an overall increase, followed by a decrease. A comparison of the changes of class interval levels in the four periods shows that the change intensity of 1990–2000 is the largest, which is 0.055%, much higher than the average change intensity ($U = 0.033\%$). This is followed by 2000–2010, which is 0.050%, while the changing intensity of the other two periods is lower than the average change intensity. Figure 5 shows that land-use intensity in this region rapidly changed in 1990–2000 and in 2000–2010. The area to change intensity during 1980–1990 was close to 0.000%, indicating that land-use intensity remained basically unchanged during this period. This area's change intensity from 2010 to 2018 was 0.025%, which is somewhat less than the average change intensity ($U = 0.033\%$) and suggests that the intensity of land use changed gradually over this time. Furthermore, the overall area and intensity of the land-use change were quite consistent, showing that the region underwent major change between 1990 and 2010 and remained largely steady between 1980 and 1990.

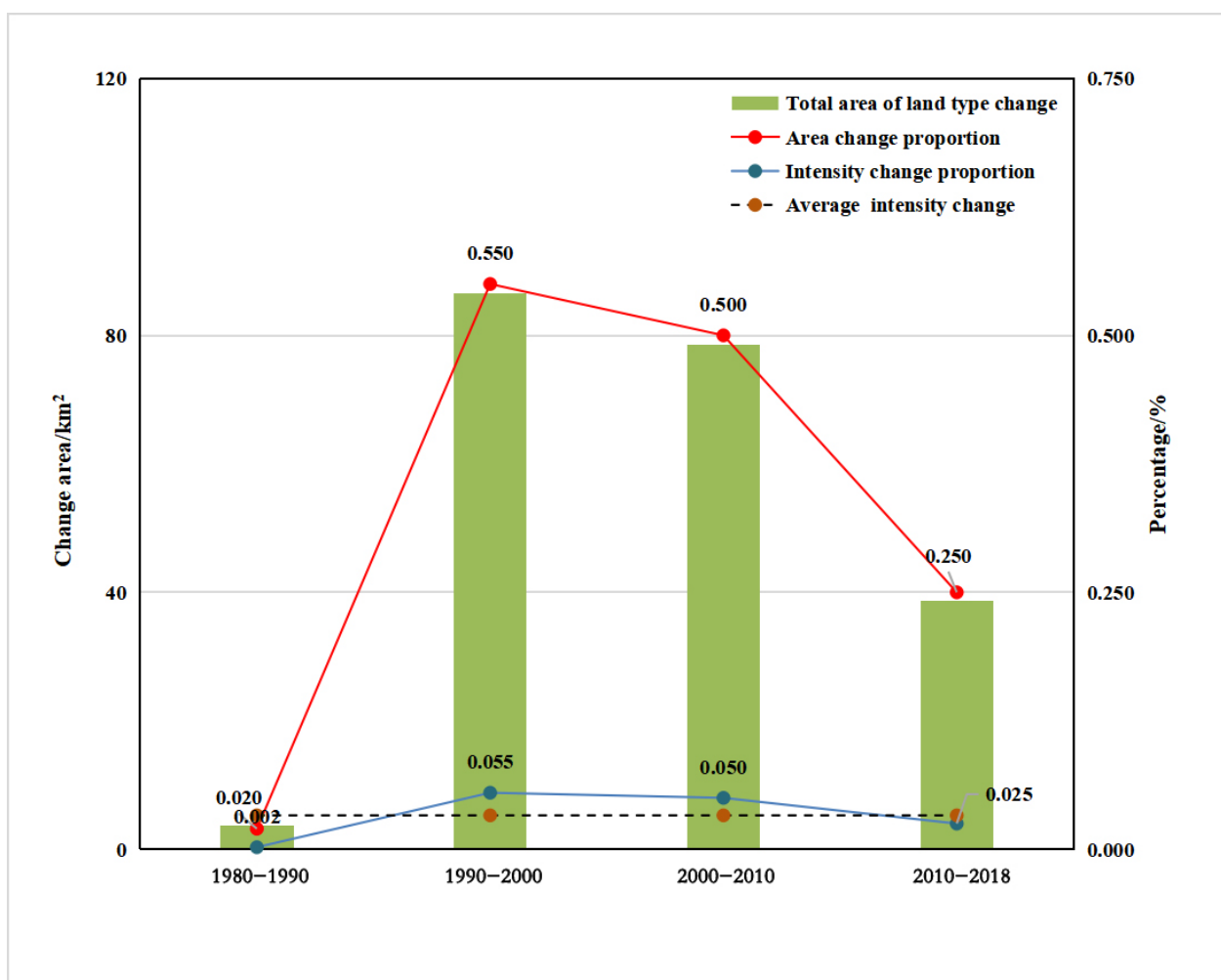


Figure 5. During 1980–2018, changes of class interval levels in the Suhai Lake Basin.

When considered as a whole, the periods 1990–2000 and 2000–2010 underwent the greatest area and intensity changes of each terrain type. The intensity of land-use change gradually reduced between 1990 and 2018, which can be a hint that the harm produced by human activity is dwindling and thus may be good news for the long-term sustainability of the ecological environment.

3.3. Spatial Heterogeneity of Land-Use Change

Through the above analysis, it is found that from the perspective of time, the changes of various types in the Suhai Lake Basin from 1990 to 2018 are relatively obvious. Moreover, spatially, a comparison of the land-use-type changes over the five periods (Figure 2) shows that the changes in the Haizi Grassland Wetland and the Suhai Lake Wetland are relatively obvious. Therefore, we selected the Haizi Grassland Wetland and the Suhai Lake Wetland from 1990 to 2018 for detailed analysis.

3.3.1. Analysis of Land-Use Change in the Suhai Lake Wetland

Specifically, the Suhai Lake Wetland (Figure 6) was dominated by the transfer outflow of swamp and saline-alkali land during 1990–2000, mainly distributed around Da Suhai Lake and Xiao Suhai Lake. During the period 2000–2010, the main transfer outflow was from the swamp, mainly distributed around Xiao Suhai Lake, where swamp to grassland accounted for the vast majority. In addition, there is a small portion of the transfer outflow of saline-alkali land. During the period 2010–2018, land-use changes were the most active.

Vast changes have taken place in saline-alkali land, grassland, and swamp, among which the transfer outflow area of grassland was the largest.

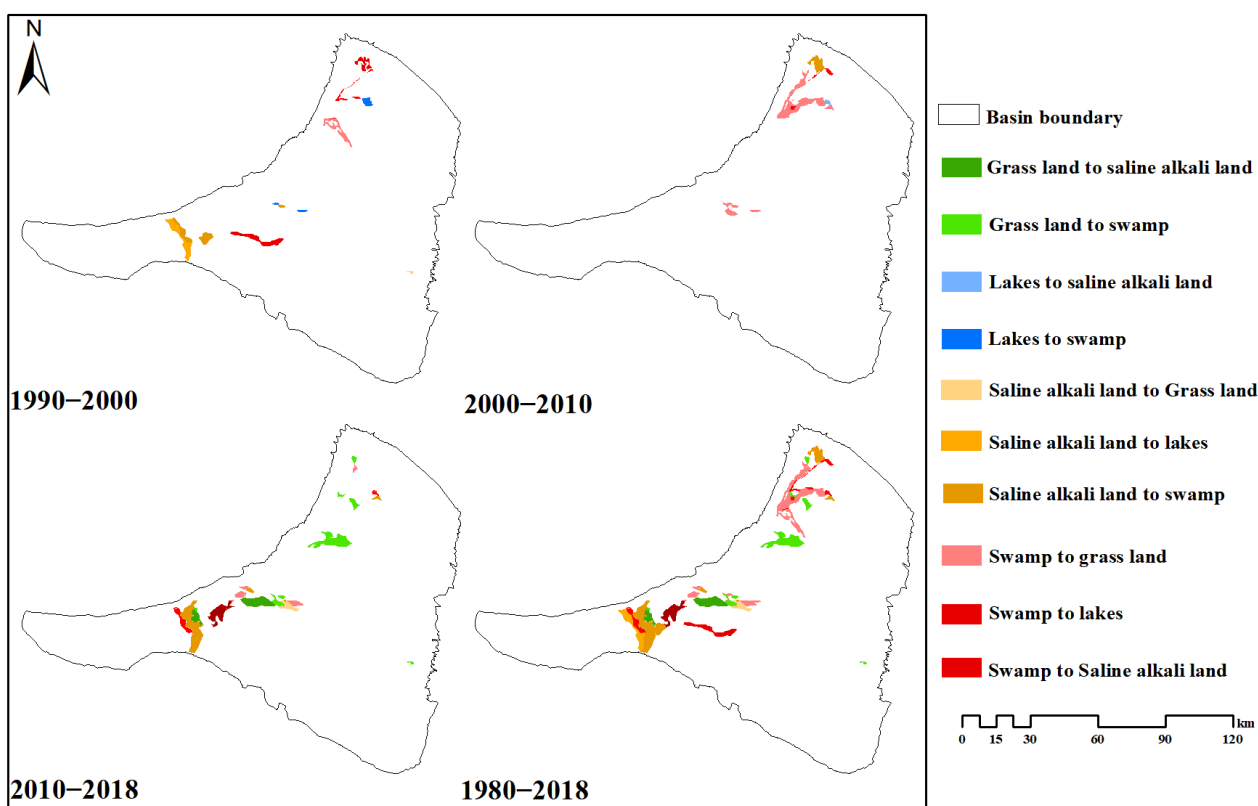


Figure 6. Distribution map of main land-use transfer flow over different periods in the Suhai Lake Wetland.

By comparing the net value of the land transfer flow of the Suhai Lake Wetland in different periods (Figure 7), we find that the grassland increased first and then has decreased since 1990–2018. The net increase of grassland area reached 11.62 km² during 1990–2010, which was echoed by the trend of swamp decreasing and then increasing. In addition, there was a net increase in swamp area of 7.48 km² and an expanding lakes area during 2010–2018. From 1990 to 2018, the area of lakes increased by 5.8 km². The area of saline-alkali land continued to shrink, but the decrease is shrinking.

Figure 8 shows that the transfer chain of land-use change in the Suhai Lake Wetland is dominated by the unidirectional chain, while the proportion of the complex chain is less than 2%. In the unidirectional chain, the proportion of the grassland–saline-alkali land chain is up to 17.65%, and the proportion of the swamp–saline-alkali land chain, the saline-alkali land–grassland chain, and the saline-alkali land–swamp chain are all more than 10%. In the reciprocating chain, the proportion of the saline-alkali land–swamp–saline-alkali land chain and the swamp–saline-alkali land–swamp chain are relatively high, close to 4%. It indicates that the major land-use change in the Suhai Lake Wetland is relatively simple, which is unidirectional, and occurs mainly among saline-alkali land, swamp, and grassland. Between 1990 and 2000, some saline-alkali land near the margin of Da Suhai Lake was devoured by the large lakes, while some swamps shrank and turned into saline-alkali land. The decreasing marsh around Xiao Suhai Lake changed mostly into grassland and saline-alkaline soil. Swamps turned primarily into grasslands around Xiao Suhai Lake between 2000 and 2010. Between 2010 and 2018, grassland deteriorated, turning some areas into saline-alkaline soil and others into swamps. Additionally, the water entering the lakes around the Da Suhai Lake increased as a result of the rising groundwater level, which led to the extension of the nearby swamp. Far away from lakes, the rise of groundwater level and

strong evaporation led to the increase of saline-alkali land area. When we compare 1980 to 2018, we see that the lakes significantly increased in size, some of the growth coming from saline-alkali land and the rest from swamp. The conversion of saline-alkaline terrain into the swamp along the margin of the Da Suhai Lake predominated. The transition out of the marsh, which was transformed primarily into grassland, dominated near the Xiao Suhai Lake.

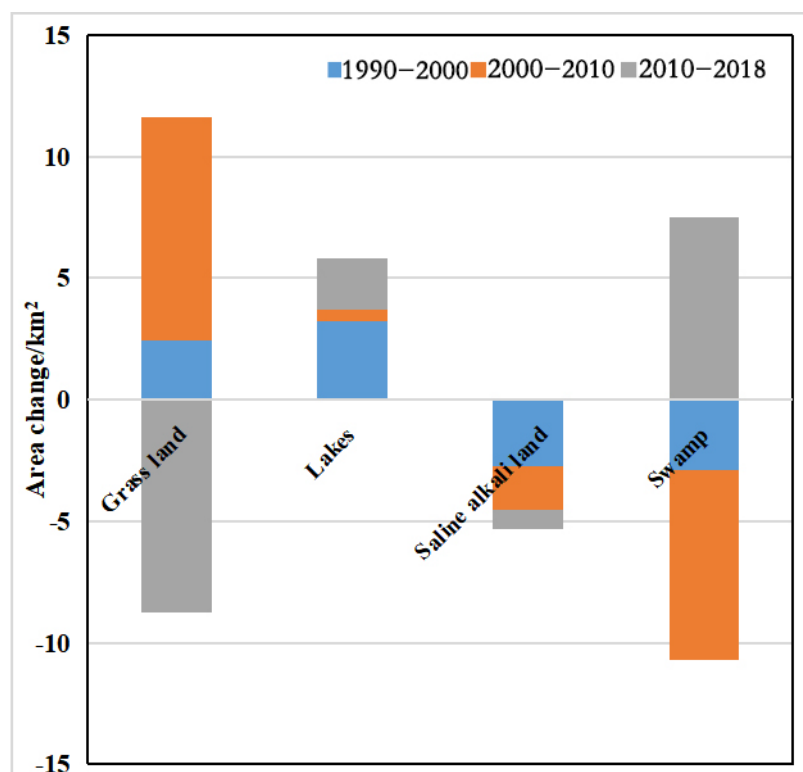


Figure 7. Net value of land transfer flow of the Suhai Lake Wetland in different periods.

Overall, the mutual land-use changes of grassland, saline-alkali land, and swamp are dominant in the Suhai Lake Wetland, accompanied by the expansion of the lakes. The transformation between terrestrial species is relatively simple. In the future, with the arrival of the glacier ablation turning point, the lakes will shrink, and the groundwater level will drop. Some plants will die because they cannot adapt to the water-shortage environment, which may lead to grassland degradation. Strong evaporation, coupled with groundwater level decline, may also lead to swamp atrophy.

3.3.2. Analysis of Land-Use Change in the Haizi Grassland Wetland

For Haizi Grassland Wetland (Figure 9), during 1990–2000, land-use change is spatially dispersed and diverse. The mainly transfer outflow is saline-alkali land and other unused land. During 2000–2010, the transfer outflow of grassland and other unused land was the most active. In addition, there were some conversions between saline-alkali land and other water land.

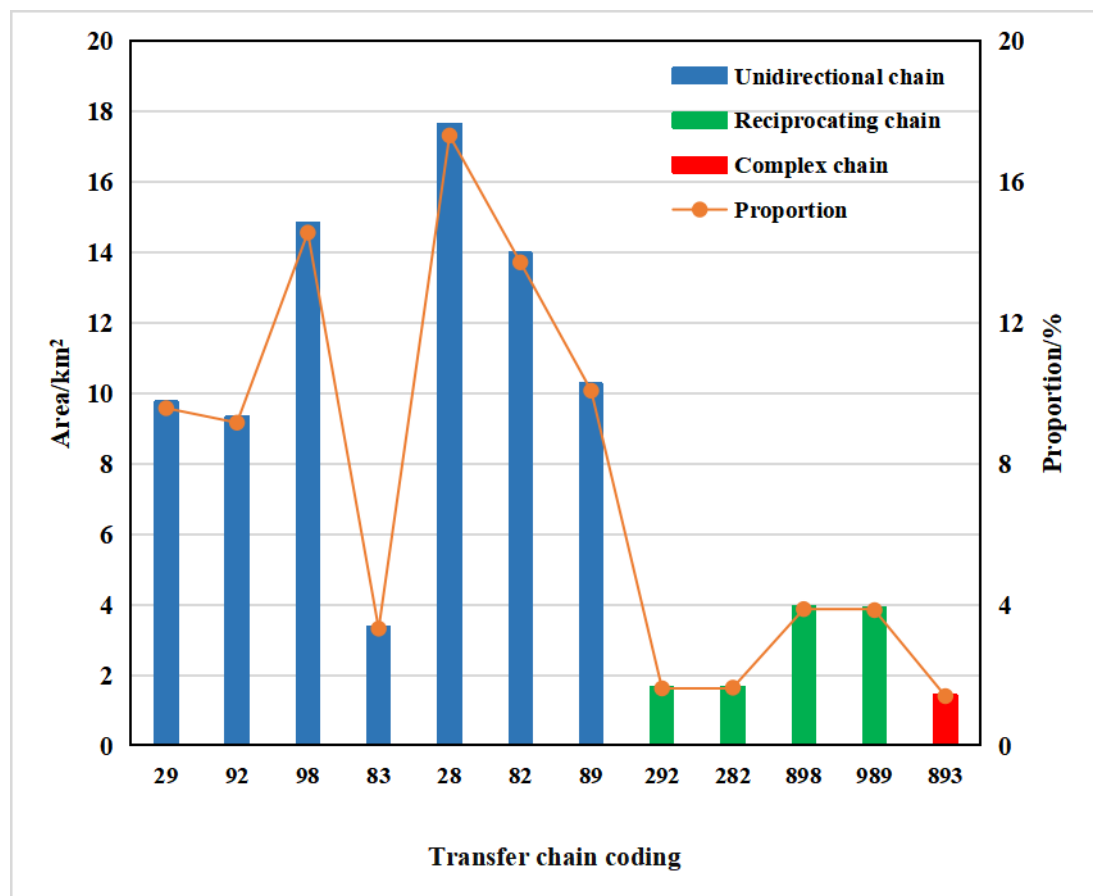


Figure 8. During 1990–2018, main transfer chain of land-use change in the Suhai Lake Wetland.

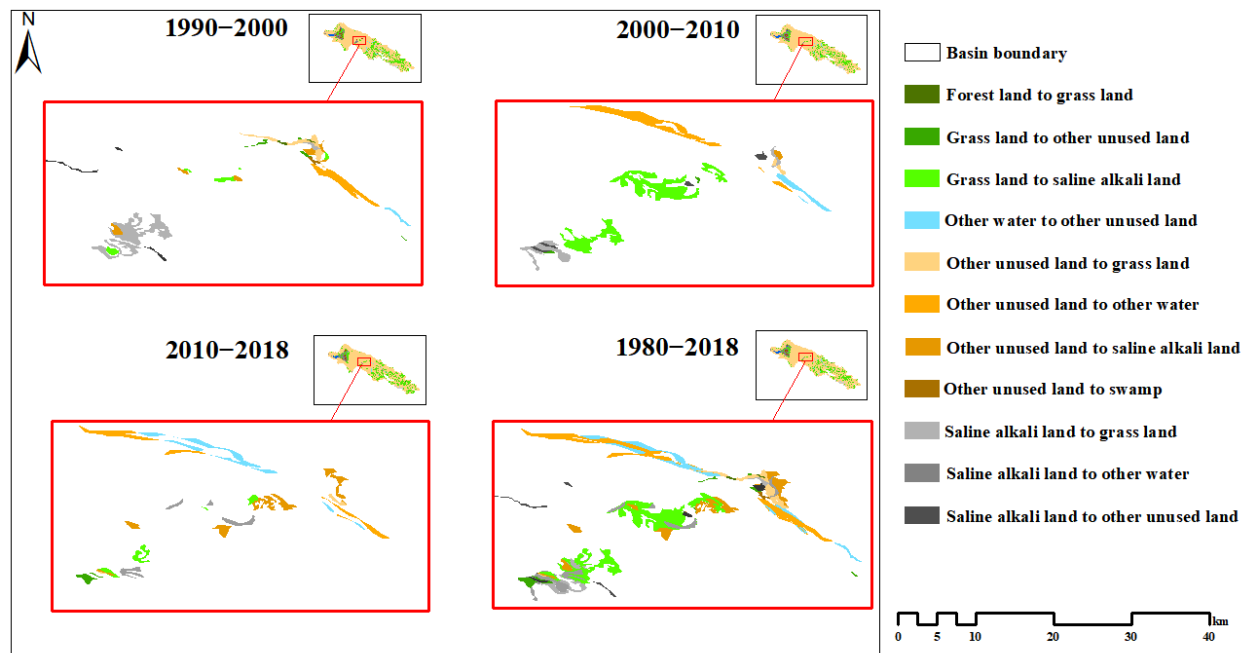


Figure 9. Distribution map of main land-use transfer flow of the Haizi Grassland Wetland in different periods.

The net value of land transfer flow in different periods indicates (Figure 10) that forest land and swamp experienced minimal changes. Grassland first increases and then

decreases, with a net increase of 19.07 km² between 1990 and 2000 and a decrease of 23.91 km² between 2000 and 2018. Correspondingly, the area of saline-alkali land first decreases and then increases, with a net increase of 33.08 km² between 2000 and 2018. The area of other water land is increasing, while the area of other unused land is decreasing.

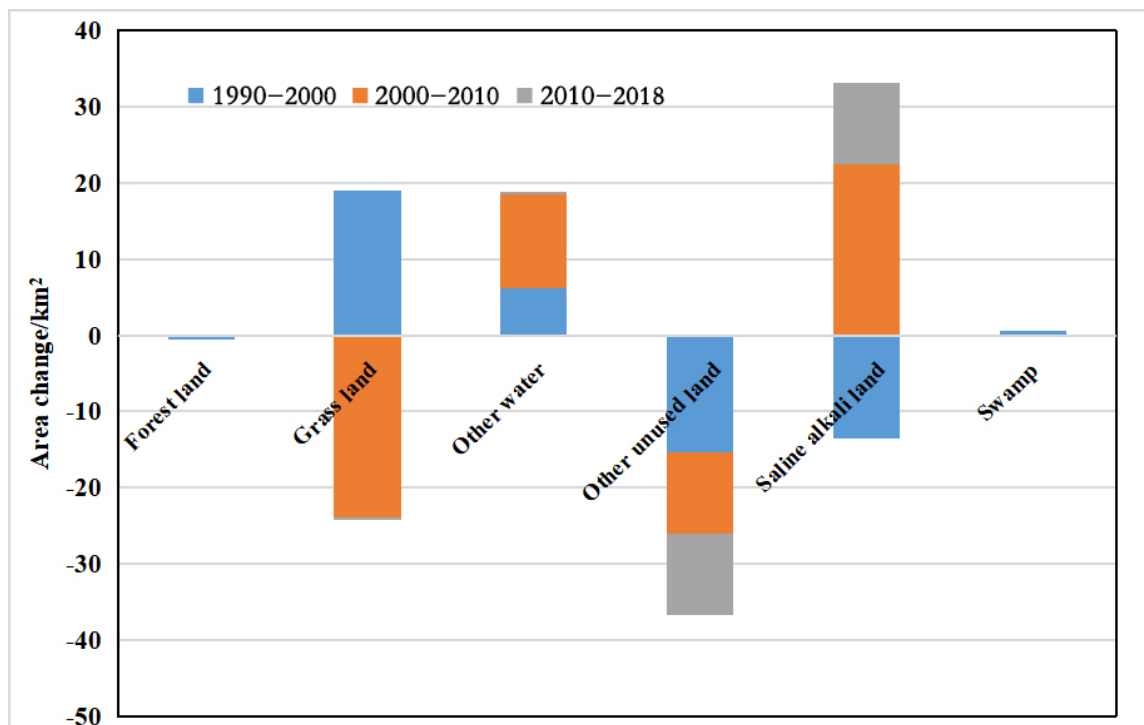


Figure 10. Net value of land transfer flow of the Haizi Grassland Wetland in different periods.

From Figure 11, it can be seen that Haizi Grassland Wetland is dominated by unidirectional chains; reciprocating chains also account for a certain proportion; and complex chains account for a small part. In the unidirectional chain, the chain from grassland to saline-alkali land accounted for the highest proportion, of 17.35%, followed by the other unused land–other water land chain and the other unused land–saline-alkali land chain, both of which account for more than 10%. In the reciprocating chain, the other unused land–other water land–other unused land chain and the saline-alkali land–grassland–saline-alkali land chain accounted for 9.82% and 10.38%, respectively, while all three types of complex chain accounted for less than 4%. It shows that the major land-use change in the Haizi Grassland Wetland is unidirectional, which is relatively simple and consisted of mainly the mutual transformation of grassland, saline-alkali land, and other unused land. Specifically, during 1990–2000, the transfer outflow of saline-alkali land and other unused land was dominant. The majority of saline-alkali land were converted into grassland and a small part into other unused land, while other unused land was converted mainly into other water land. During 2000–2010, the grassland was transferred mainly out and converted mostly into saline-alkali land. In addition, the river basin area increased, and some other unused land was submerged. During 2010–2018, the conversion of other unused land and other water land dominated, and a small proportion of the seasonal river basin area was converted to other unused land. The other unused land was converted mainly into saline-alkali land, and a small part was converted into other water land. Looking at the years 1980–2018, we find that compared with 1980, the area of grassland and other unused land decreased, and the area of saline-alkali land and other water land increased in 2018.

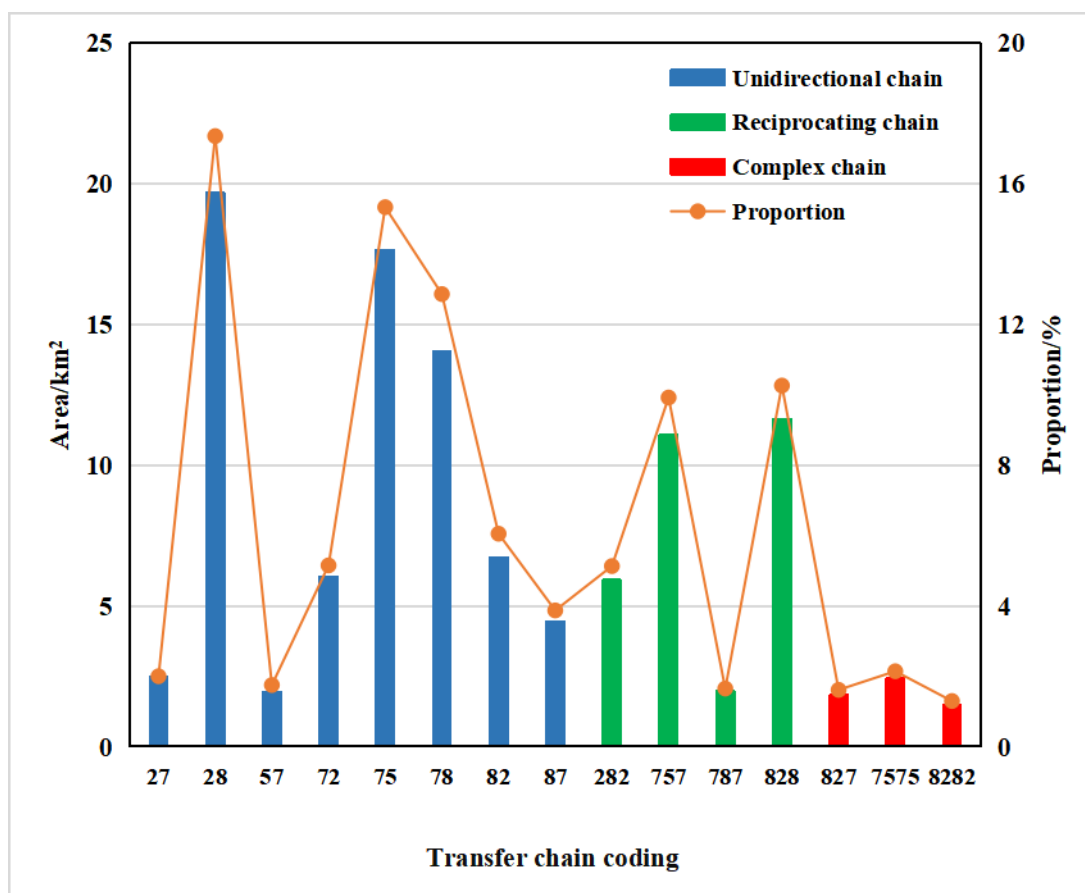


Figure 11. During 1990–2018, main transfer chain of land-use change in the Haizi Grassland Wetland.

In general, the conversion of land use in the Haizi Grassland Wetland is a process of grassland, from increase to degradation owing to the increased salinization of the soil, while the expansion of the river basin area leads to a decrease in the area of other unused land. Therefore, strengthening soil salinization management, thus reducing grassland degradation, is a necessary measure for environmental protection in this region.

4. Discussion

4.1. Driving Factors of Land-Use Change in the Suhai Lake Basin

The land-use transfer chain in the Suhai Lake Basin is dominated by the unidirectional chain, but there are also reciprocating chains and complex chains, which are the results of climate change and human activities.

4.1.1. Natural Factors

With global warming, glaciers are melting on a large scale [38]. The Suhai Lake Basin has a total glacier area of 135.8 km², but that decreased by 29.5 km² between 1980 and 2018. The bare land formed after the glacier retreat will be dominated by primary succession, but the growth of herbaceous plants is limited owing to the perennial low temperature and poor soil in the glacier area [39]. As a result, bare unused land was formed after the glacier retreated. At the same time, owing to the increase of glacier melting water and precipitation (Figure 12), the mountain runoff of the Da Haltang River and Xiao Haltang River showed an increasing trend, which led to the rise of groundwater level and the expansion of the lake in the middle and lower reaches of the Suhai Lake Basin. With the continuous strengthening of the salinization of saline soil led by the increase of temperature and evaporation, some grassland was transformed into swamp and saline-alkali land. This is the fundamental

reason for the expansion of swamp and saline-alkali land in the Haizi Wetland and the Suhai Lake Wetland, which are in the middle and lower reaches of the basin.

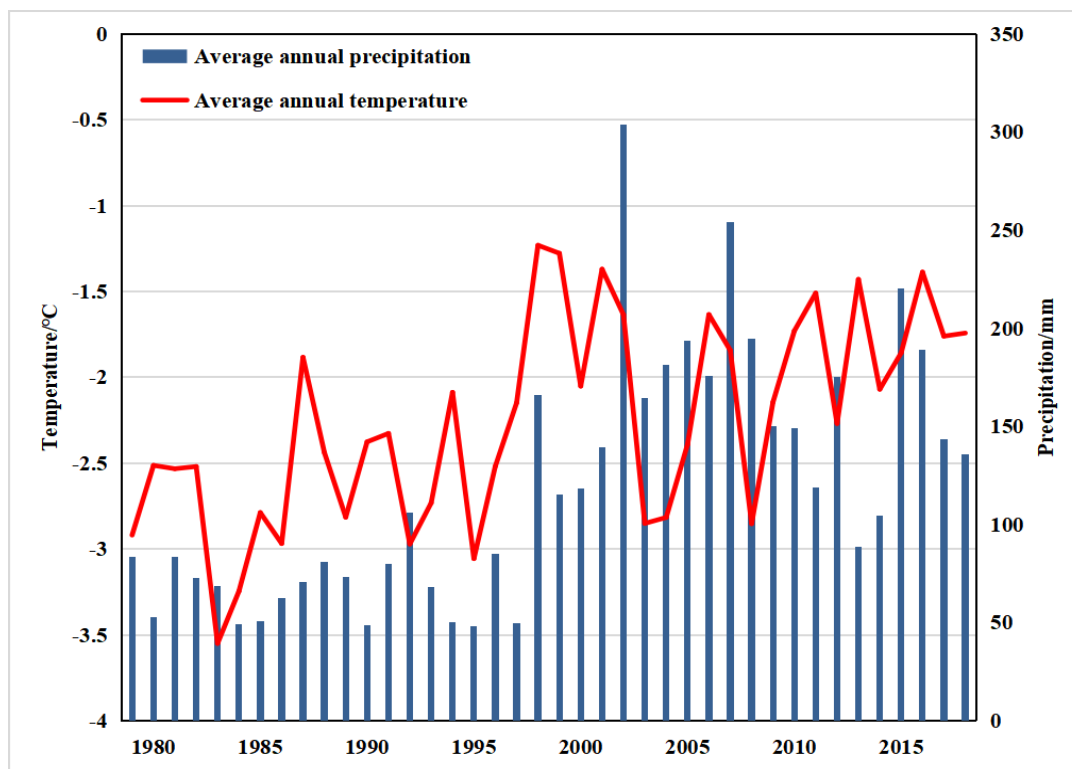


Figure 12. During 1980–2018, Suhai Lake Basin climate change.

4.1.2. Economic and Policy Factors

As an important part of the ecological security barrier of the Qinghai-Tibet Plateau, the Suhai Lake Basin has important ecological value, so the state has introduced a series of policy supports.

In 1982, the provincial government approved the establishment of the provincial Migratory Bird Nature Reserve in Da Suhai Lake. The Third Session of the 13th People's Congress of Aksai Kazakh Autonomous County adopted and promulgated the 'Regulations on Grassland Management of Aksai Kazakh Autonomous County'. In the 1990s, more than 20 million yuan was invested into the Suhai Lake Basin. The grassland infrastructure construction was strengthened. The construction of the first and second grassing bases for disaster prevention and the conservation of animal husbandry was implemented. The degradation, desertification, and salinization of grassland were comprehensively managed. Moreover, there were the restoration and the construction of natural grassland, a grazing withdrawal project, and so on. A total of 4360 mu of artificial grassland and 24,700 mu of improved grassland were constructed. The implementation of a series of policies effectively curbed the trend of grassland's degradation, desertification, and salinization. Grassland resources, as well as the further ecological environment of the basin, were protected, making the area of saline-alkali land in the Haizi Grassland Wetland shortly decrease from 1990 to 2000. In addition, some other unused land was developed into grassland. Similarly, policy implementation also effectively restrained the increase of saline land area in the Suhai Lake Wetland and expanded the grassland area. In 2003, China launched the wetland protection project, which included the Da Suhai Lake Wetland and the Xiao Suhai Lake Wetland in the list of important wetlands in China, to further strengthen the restoration and protection of wetland resources.

4.2. Ecological Problems in the Suhai Lake Basin from the Perspective of Land-Use Change

First, through the analysis of grassland area change, we found that in the early stage of grassland management, Aksai County implemented the grassland contract responsibility system. They achieved certain results by using a four-season pasture rotation or a grazing prohibition. The increase in grassland area indicates that rotational grazing or a grazing prohibition is one of the effective measures for grassland restoration. However, grassland degradation occurred again after 2000, which was not only related to the increase of precipitation and the rise of groundwater level but also affected by the intensity and time of the grazing prohibition. Owing to an excessive grazing prohibition, soil phosphatase activity was inhibited, and the decomposition and transformation of organic phosphorus were affected. At the same time, the soil nitrogen cycle was also affected, and soil bulk density and soil organic matter content decreased, which reduced the plant density and species richness of the grassland. The long-term grazing ban will lead to the degradation of grassland vegetation and soil nutrients [40,41]. It follows that the optimal prohibition time may vary under different conditions [42]. Therefore, it is necessary to delineate the spatial distribution range of rotary and forbidden grazing grasslands and determine the optimal grazing prohibition time by combining the basin hydrothermal and topographic conditions and a scientific assessment of grassland degradation processes and grassland carrying capacity [43–45]. In addition, scientific grassland and wetland conservation and rehabilitation programs were developed to ensure sustainable watershed development.

Second, in the source area of the upper Suhai Lake Basin, the area of bare unused land formed by melting glaciers is 5.41 km², and the formation of soil for vegetation growth is a complex and lengthy process, which leads to the desertification process in the upstream source area. With the further ablation of glaciers, the area of bare land will continue to increase in the future, which without timely intervention and correct management will lead to the further aggravation of soil desertification in the region. At the same time, with the glacier melting to a certain extent, there will one day be a turning point. Glacier runoff will continue to decrease, which will lead to the shrinkage of lakes and swamps in the middle and lower reaches of the basin. Vegetation succession will intensify, and the ecological environment will deteriorate. Therefore, it is necessary to further strengthen the research on the spatial coupling mechanism of water–soil–vegetation in the Suhai Lake Basin and make scientific predictions for its future trends, so as to provide scientific support for formulating scientific coping strategies.

5. Conclusions

The Suhai Lake Basin is located at the northern edge of the Qinghai-Tibet Plateau, with vital ecological status and a fragile ecosystem. The function of the ecosystem services has been compromised because of the interference of climate change and human activities, and there are significant ecological and environmental issues that directly endanger the safety of the Suhai Lake Migratory Bird Nature Reserve and the way of life of the Kazakh residents. This study introduces the idea of land-use transfer flow in an original way and analyzes the process, the affecting variables, and the issues of land-use changes in the Suhai Lake Basin over the past 40 years, by using the relatively novel methodologies of interval level change and the land-use transfer chain. Finally, it analyzes and predicts the potential ecological problems of the future from the perspective of land-use change. The main conclusions are as follows.

The most noticeable changes in the Suhai Lake Basin from 1980 to 2018 are in the grassland, saline-alkali land, and swamp, which are accompanied by glacier melting and lake extension. The changes in land-use types, however, vary across time. The greatest intensity of land-use change occurred between 1990 and 2000, at 0.055%. The grassland area grew by 23.07 km², primarily owing to the transfer of useless land in the middle and lower reaches, such as swamps, saline-alkali land, and other lands. Because of the three ecological issues with grasslands being managed by the Kazakh Autonomous County and grazing ban, the Suhai Lake Wetland and the Haizi Grassland Wetland were restored, and the saline land

was effectively managed. However, after 2000, as the climate continued to warm, glacial meltwater and precipitation increased, the groundwater level in the middle and lower reaches rose, soil salinization increased, the saline-alkali area increased by 10.04 km², the swampland shrank (with a net decrease of 7.62 km²), and grassland degradation occurred, in which the grassland area decreased by 45.46 km² during 2000–2018.

Spatially, the land-use changes in the Suhai Lake Basin are most obvious in the Suhai Lake Wetland and Haizi Grassland Wetland. The land-use changes in the Suhai Lake Wetland are relatively simple and mainly unidirectional, while the land-use changes in the Haizi Grassland Wetland are more complex, with the total proportion of reciprocating chains and complex chains reaching 30.52%. In addition, the glacial retreat was in the upstream source area, with increased bare land and unused land.

The primary ecological issues in the upstream source region of the Suhai Lake Basin were land exposure and ecological degradation in the glacial retreat zone, created by the glacial retreat. Additionally, the transition between lakes, swamps, saline-alkali land, and grassland was greatly influenced by the water recharge conditions in the middle and lower parts of the basin. The degradation of the grassland can be brought on by both excessive grazing and overprotection. As a result, future research must focus more on the following areas: how to determine the appropriate grazing and grazing ban intensity; the ecological succession process and governance of the glacier retreat zone; and the water recharge process and lake response in the middle and lower reaches of the watershed under future climate change.

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