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Characteristics of Land Use/Cover and Macroscopic Ecological Changes in the Headwaters of the Yangtze River and of the Yellow River over the Past 30 Years

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Abstract: Based on land use and land cover (LULC) datasets in the late 1970s, the early 1990s, 2004 and 2012, we analyzed characteristics of LULC change in the headwaters of the Yangtze River and Yellow River over the past 30 years contrastively, using the transition matrix and LULC change index. The results showed that, in 2012, the LULC in the headwaters of the Yellow River were different compared to those of the headwaters of the Yangtze River, with more grassland and wet- and marshland. In the past 30 years, the grassland and wet- and marshland increasing at the expense of sand, gobi, and bare land and desert were the main LULC change types in the headwaters of the Yangtze River, with the macro-ecological situation experiencing a process of degeneration, slight melioration, and continuous melioration, in that order. In the headwaters of the Yellow River, severe reduction of grassland coverage, shrinkage of wet- and marshland and the consequential expansion of sand, gobi and bare land were noticed. The macro-ecological situation experienced a process of degeneration, obvious degeneration, and slight melioration, in that order, and the overall change in magnitude was more dramatic than that in the headwaters of the Yangtze River. These different LULC change courses were jointly driven by climate change, grassland-grazing pressure, and the implementation of ecological construction projects.

Keywords: LULC change; comparative analysis; remote sensing; headwaters of the Yangtze River; headwaters of the Yellow River

1. Introduction

Land is the most basic natural resource that human beings depend on for existence and development, and LULC change is the direct manifestation of the effects of human activities on the natural ecosystems [1]. Numerous studies have showed that LULC change could affect the ecosystem structure and services and further impact human beings [2–4] by changing the energy and matter flows, biosphere-atmosphere interactions, biogeochemical cycles, surface radioactive forcing, biodiversity and the sustainable utilization of environmental resources at local and/or regional levels [5–7]. Meanwhile, LULC change detection is an important tool for identifying geographical dynamics and its association with human activities, such as urbanization [8,9], desertification [10,11], deforestation [12] and other cumulative changes [7]. Thus, LULC change has become an important theme in global climate and ecosystem change research [13].

Remote sensing is the most common technique for characterizing LULC currently, because of its capacity to provide a digital, accurate and objective LULC inventory, which can be processed by computer in a batch mode, and in a cost-effective and timely manner, with suitable spatial resolution for land resource and environment management [6,14,15]. In addition, remote sensing makes the LULC change detection possible by the supplying of multi-temporal and historical data [6,15]. Since LULC change detection and monitoring by remote sensing involves the use of several multi-date images, the degree of success depends mainly upon the accuracy of image classification [16]; thus, an adequate understanding of landscape features, eco-environment characteristics and image processing systems is necessary [17]. The pixel-based post-classification comparison methodology is the most common approach and makes a successful change detection possible, with the ability to use images acquired from diverse sources with different spatial and spectral resolutions [6,18]. The post-classification comparison goes beyond simple change detection and provides "from-to" change information quantitatively [14,16,19]. However, this technique requires high classification accuracy for every image and a heavy workload.

The Three-River Headwaters Region (TRHR), which is known as the "Chinese Water Tower," is the source region of the Yangtze River, Yellow River and Lancang River and of key importance to the ecological security of China and Southeastern Asia (Figure 1). However, owing to the high altitude and harsh natural condition, the eco-environment in the TRHR is highly fragile and sensitive to climate change. Recently, the structure and functions of the ecosystem in this area have undergone severe degradation owing to the impact of rapid climate change and intense human activities, which posed a serious threat to the ecological security of regions downstream from the TRHR [20]. With these considerations, the State Council approved *the Ecological Protection and Construction Master Plan of Qinghai Sanjiangyuan Nature Reserve* in 2005, including 22 projects such as forbidding grazing, combating desertification, and human-induced rainfall.

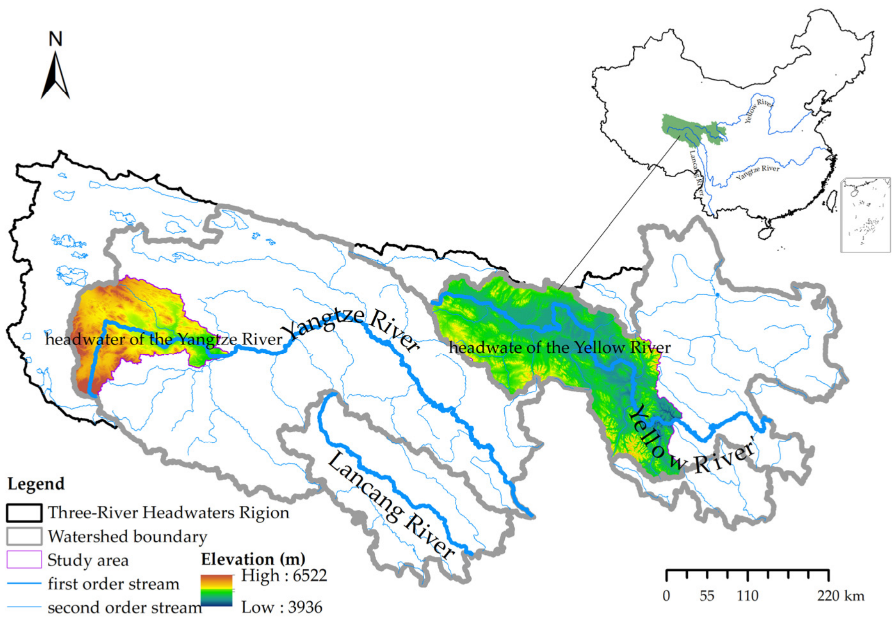


Figure 1. Location of the Three-River Headwaters Region and study areas.

International and domestic researchers have conducted many studies at both the regional and local scales on LULC change in the TRHR. Xu *et al.* [21] analyzed the land-use dynamic degree in the TRHR, and found that the spatial patterns of ecosystem change have been stable and rather slow during the last 30 years compared to other places in China. Shao *et al.* [22,23] reported that, after the implementation of the ecological projects, the ecosystem degradation in the TRHR has basically been contained, and the conditions have been partially meliorated. Liu *et al.* [24] found that the vegetation coverage in the TRHR displayed an upward trend under the combined effects of climate change and the projects based on the analysis of the NDVI dataset from 2000 to 2011. Huang *et al.* [25] indicated that, comparing before and after 2004, the area of grassland deterioration increased slightly, while the grassland coverage showed significant increase. However, these researchers focused mainly on single LULC type, specifically grassland and wetland [26], or performed their studies on regional or local scales; few works have involved contrastive analyses of different headwater regions that could show the spatial heterogeneity in LULC change in the TRHR more efficiently. Meanwhile, LULC types have different impacts on ecosystems and their services [15], and LULC change detection have increasingly been recognized as one of the most effective tools for natural resource management [18]. However, many previous works only focused on the characteristics of LULC change, and further discussion of ecosystem situations and their service changes was lacking, or simulated using a mass of data and complicated models. Under this consideration, we defined the LULC change index to evaluate the change of macro-ecological situation in a simple and convenient manner, despite the complicated calculations of different ecosystems services.

To explore the temporal and spatial variations in LULC change of the TRHR, the headwaters of the Yangtze River and Yellow River were selected for performing the contrastive analysis. In this study, the headwaters of the Yangtze refer to the Tuotuo River basin, which is one of the primary glacier regions in the source region of Yangtze River, and the headwaters of the Yellow River refer to the headwater region above the Jimai hydrological station [27]. Based on LULC datasets of the late 1970s, the early 1990s, 2004 and 2012, the LULC and macro-ecological situations and changes in the headwaters of the Yangtze River and Yellow River were analyzed contrastively by applying the transition matrix and LULC change index. The aim of this study was to enhance our understanding of LULC and macro-ecological situations and changes in the headwaters of the Yangtze River and Yellow River, and provide scientific reference for the rehabilitation and reconstruction of integrated ecosystem services in different geographical locations in the TRHR.

2. Study Area

The headwaters of the Yangtze River are located between 90°23′–93°08′E and 33°42′–34°45′N, covering 1.94×10^4 km^2, with tributaries such as Zhamuqu. The headwaters of the Yellow River are located between 95°53′–99°53′E and 33°02′–35°20′N, covering 4.39×10^4 km^2, with tributaries such as Duoqu and Requ. While the elevation of the headwaters of the Yangtze River, with an extensive and concentrated distribution of glaciers, range between 4458 and 6522 m, the elevation of the headwaters of the Yellow River, where the terrain is flat and wide, range between 3936 and 5329 m (Figure 1). The headwaters of the Yangtze River, located in the hinterland of the Qinghai-Tibet Plateau, are cold and dry, and the annual average temperature and precipitation during the period between 1975 and 2012 were −3.77 °C and 291.79 mm, respectively. The headwaters of the Yellow River, located in the transition zone between the semi-arid and sub-humid zones, have a plateau continental climate, having no significant seasons, and the annual average temperature and precipitation during the period between 1975 and 2012 were −2.32 °C and 451.37 mm, respectively.

3. Data and Method

3.1. RS Images Processes

Based on the MSS (Multispectral Scanner) images with 80 m spatial resolution in the late 1970s (June, July and August of 1976 and 1977), TM (Thematic Mapper) images with 30 m spatial resolution in the early 1990s (July, August and September of 1990, 1991, and 1992) and in 2004 (June, July, August and September of 2003, 2004, and 2005), and HJ-1 images (mini-satellite constellation for environment and disaster monitoring) with 30 m spatial resolution in 2012 (July, August and September of 2012), the LULC datasets (1:100,000 scale) were developed for the TRHR for the four above-mentioned time periods. After a series of image processing steps such as radiometric calibration, atmospheric correction, single band extraction, false color composition, geometric correction, histogram equalization, images mosaic, and segmentation, human-computer interactive interpretation, which could increase the overall classification accuracy by approximately 10% [14], was conducted to construct the LULC datasets based on the Chinese LULC classification system proposed by Liu *et al.* [28,29], which was supplemented by field investigation data, a grassland map (1:1,000,000 scale), a vegetation map (1:1,000,000 scale), a topographic map (1:100,000 scale), *etc*. After the classification accuracy assessment and modification, the boundaries of the headwaters of the Yangtze River and Yellow River were used as masks to extract the LULC data for the comparative analysis. The workflow of this integration is displayed in Figure 2.

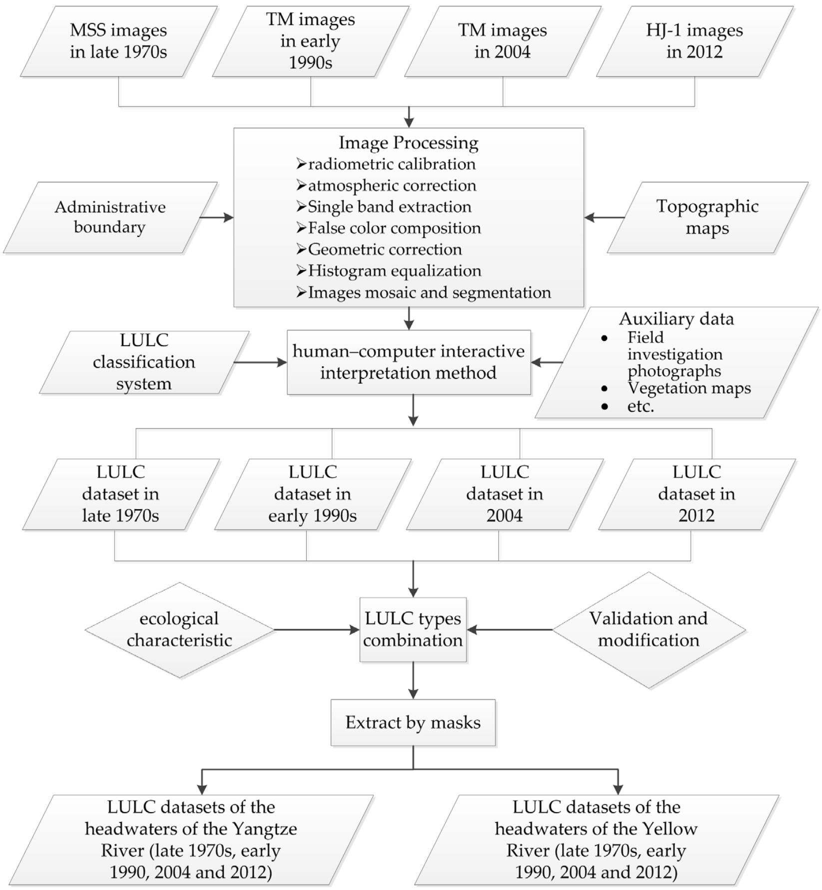


Figure 2. The technical process of acquiring LULC dataset.

In order to facilitate statistical analysis, we adjusted and combined the LULC types into a total of 9 types, according to the ecological characteristic of each LULC type (Table 1).

Table 1. LULC classification scheme.

Types in this Study	Chinese LULC Classification System [28,29]	Description
forest	21 forest land 23 sparse forest land 24 other forest	Arbor, including timber forest, commercial forest, protection forest and others
shrub	22 shrub	Scrub with the height lower than 2 m and shrubbery
high-coverage grassland	31 high-coverage grassland	Grassland with the coverage higher than 50%
medium-coverage grassland	32 medium-coverage grassland	Grassland with the coverage between 20% and 50%

Table 1. *Cont.*

Types in this Study		Chinese LULC Classification System [28,29]	Description
low-coverage grassland		33 low-coverage grassland	Grassland with the coverage between 5% and 20%
wet- and marshland	Water bodies	41 stream and rivers 42 lake 43 reservoir and ponds	Natural water bodies, wetland, and land for water conservancy facilities
	permanent ice and snow	44 permanent ice and snow	
	shoaly land and swamp	46 shoaly land 64 swamp	
build-up area		51 urban land 52 rural residential area 53 other construction land	Residential, commercial and services, industrial, transportation
sand, gobi and bare land		61 sand land 62 gobi 63 saline-alkali soil 65 bare land 66 bare rock	Land covered with sand, gravel or soil with the vegetation coverage lower than 5%, or land covered with saline-alkali
desert		67 other unused land	alpine desert, tundra, *etc*.

3.1.1. Image Pre-Processing

To reduce the effects of atmospheric scattering and absorption, atmospheric correction was conducted using the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) algorithm. The FLAASH is a kind of physical method based on a radiative transfer model considering different atmospheric optical properties during the image acquisition and is observed to be more precise than the dark-object subtraction (DOS) method, which is an image-based technique, especially in grass sites [30,31].

After atmospheric correction, a false color composite was performed: TM images—band 4, 3 and 2; MSS images (Landsat 1–3)—band 7, 5 and 4; MSS images (Landsat 4, 5)—band 4, 2 and 1, in order to depict different LULC classes more accurately, especially vegetation types.

Geometric correction of the images was carried out using a master-slave approach [6]. The 2004 images were previously geo-referenced using topographic maps (1:100,000 scale); thereafter, with the aid of the 2004 images as references, satellite data of other three periods mentioned above were rectified to a common geometric system. A minimum of 9 evenly distributed points was used in the correction process for every image. In addition, the patches that kept stable should be overlaid accurately. Images were geo-referenced using the quadratic polynomial and finite element method and were resampled using the nearest neighbor method. The root mean squared error (RMSE) of geometric correction was less than 1.5 pixels (45 m for TM and HJ-1 images and 120 m for MSS images).

The histogram equalization method was conducted to perform image enhancement, which was meant to improve the visual interpretability of the RS images by increasing the apparent distinction between features [14].

3.1.2. Classification Methodology

After a series of image processing steps, human-computer interactive interpretation under overall digital environment was conducted to construct the LULC datasets with the field survey data, vegetation map, topographic map and grassland map as auxiliary data. The LULC map of 2004 was constructed first.

To guarantee the classification accuracy and efficiency, we performed the interpretation for the 1970s, 1990s and 2012 RS images by extracting the change information directly from the comparison with the RS images in 2004. After the fusion of the change information for the period of the late 1970s–2004, the early 1990s–2004 and 2004–2012 and the LULC map of 2004, the LULC maps of the late 1970s, the early 1990s and 2012 were eventually constructed. However, the spatial resolution of

MSS was 80 m, which can cause low classification accuracy [6]. Under this consideration, we set the topographic map with a scale of 1:100,000 produced in the early 1980s as another information source, which was an effective supplement for the interpretation.

To improve the classification accuracy, information from the grassland map, the vegetation map and the topographic map was fully obtained; the horizontal zonality and vertical zonality of LULC distribution, the effect of topography on spatial distribution of LULC and change of main LULC types, especially grassland, glacier and water bodies, were all of interest as well.

3.1.3. Accuracy Assessment

Note that, owing to subjective factors in the interpretation process, spectrally similar responses from different LULC types and blurred texture features, interpretation error was inevitable. Thus, performing accuracy assessment for LULC classification was essential. Random sample checking by field survey points and checking line were adopted. In 2004, 2005 and 2012, we conducted 3 field surveys in the TRHR to obtain ground truth data, and the field survey materials and records were used to assess the classification accuracy of the LULC maps of 2004 and 2012 (Figure 3).

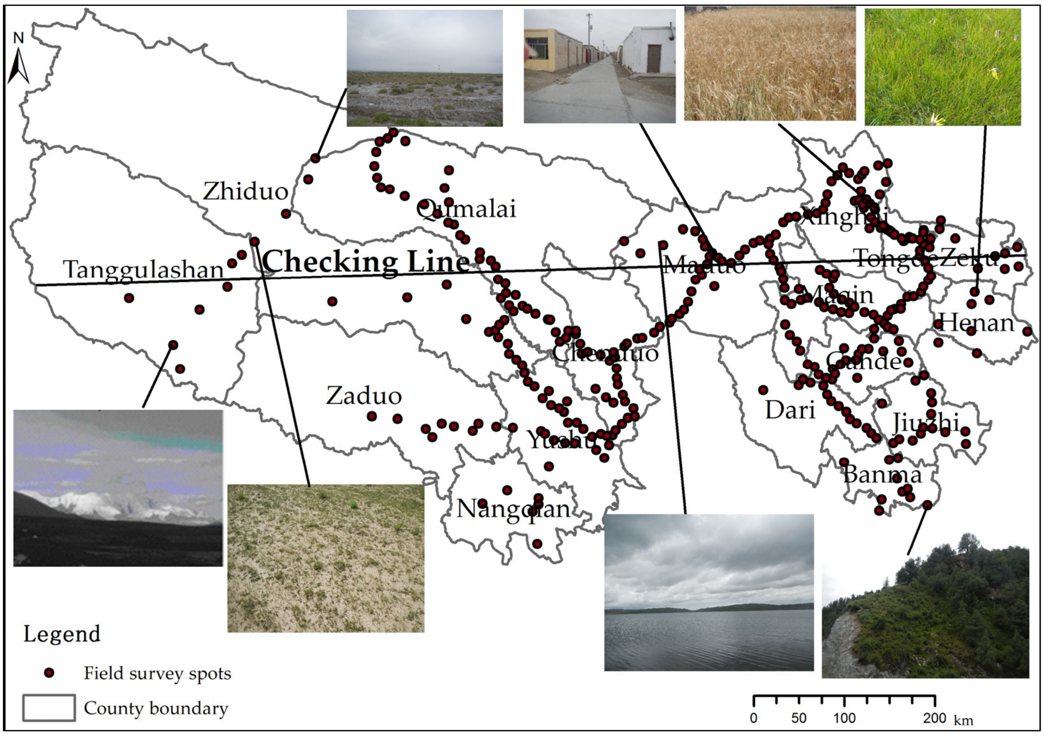


Figure 3. The spatial distribution of the field survey points and checking line.

339 reference points were extracted randomly from 2068 points recorded by handheld GPS acquired from the field surveys in 2004 and 2005, and the records were used to assess the classification accuracy of the LULC dataset of 2004. The result showed that there were 15 reference points where LULC were misclassified. Thus, the accuracy assessed by survey points was 95.58%. The checking line in Figure 3 involved 1903 patches. 421 patches were extracted randomly and were used to assess the classification accuracy one by one. According to the assessment result, there were 18 patches where LULC were misclassified. Thus, the accuracy assessed by checking line was 95.72%. In general, there were 33 misclassifications among the 760 random checks, and the overall accuracy of the LULC dataset of 2004 was 95.66%. The same method was adopted in the accuracy assessment of the LULC map of 2012, and the overall interpretation accuracy was 96.01%.

3.2. Detection of LULC Change

Vector LULC datasets with 1:100,000 scale in the late 1970s, the early 1990s, 2004 and 2012 were rasterized to perform raster-based change analysis with 100 m spatial resolution. Using GIS overlay function, the LULC transition matrix was computed, and change statistic was calculated on a pixel-by-pixel basis between each pair of LULC maps (*i.e.*, the late 1970s to the early 1990s, the early 1990s to 2004, and 2004–2012). It not only locates changes but also quantifies the different types of change with "from-to" change information [14,16].

3.3. Land Use/Cover Change Index

LULC change has been identified as one of the most important drivers of change in ecosystems and their services [32,33]. However, information about the consequences of LULC change for ecological situations and ecosystem services is largely absent or hard to find, and the LULC dynamic degree model used in previous research [21] can only evaluate the LULC change magnitude and does not indicate the change in ecological situation. To convert LULC statistics into measures of macro-ecological situation changes in a convenient manner, we graded 8 out of the 9 LULC types (excluding the build-up area) listed in Table 1 based on ecosystem services value of each LULC type and the extent to which the transitions between different LULC types influenced the delivery of ecosystem services (Table 2). Estimates were based on a mix of expert knowledge, literature sources [34,35] and the natural situation of the TRHR—for the "Chinese Water Tower," water regulation and supply are the most important services of the TRHR, followed by soil conservation, and then by the supply function, climate regulation and carbon mitigation [22]. A higher ecological level value indicates that the LULC change will impact the macro-ecological situation and ecosystem services more significantly, and *vice versa*.

Table 2. Ecological levels of different LULC types.

LULC Types	Water and Marsh Land	Forest	Shrub	HCG	MCG	LCG	Desert	Sand, Gobi and Bare Land
ecological level	8	7	6	5	4	3	2	1

The LULC change index considers both the change of areas and the ecological levels. It is calculated as:

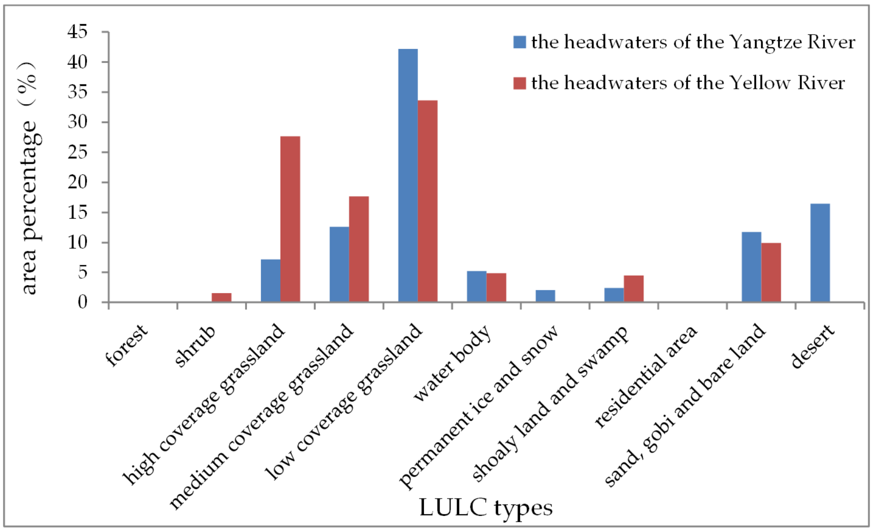
$$LCCI = \sum_{k=1}^{n} [A_k \times (D_{ak} - D_{bk})] / A \times 100\% \quad (1)$$

where: $LCCI$ is the LULC change index; k = 1, 2, 3, 4, 5, 6, 7, 8 represents the LULC types; A_k is the area of the LULC change; D_{ak} is the ecological level after change; D_{bk} is the ecological level before change; and A is the total area of the research region. A positive value means that the LULC changes in a positive way and the macro-ecological situation meliorates, and *vice versa*.

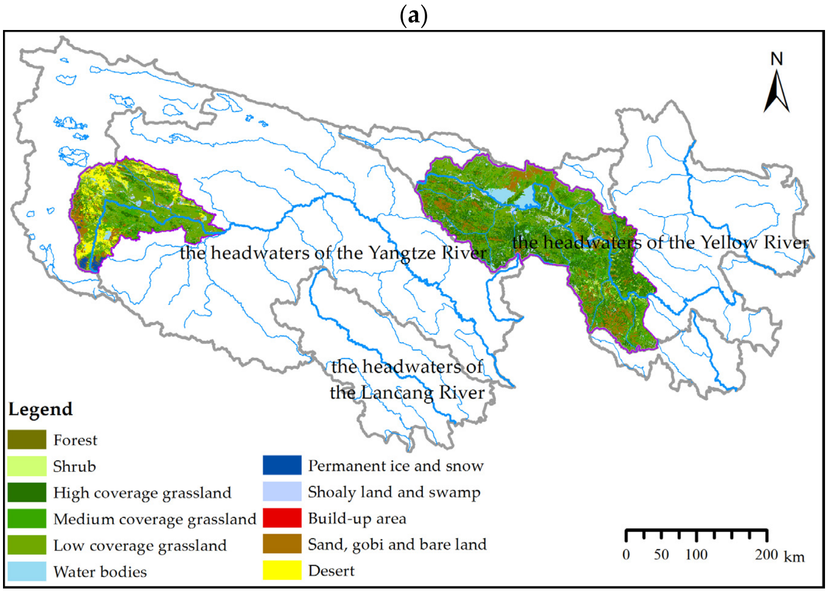
4. Results

4.1. Land Use/Cover Conditions

In 2012, the dominating LULC type in the headwaters of the Yangtze River were grassland, with the high-coverage grassland accounting for 7.23%, the medium-coverage grassland accounting for 12.64% and the low-coverage grassland accounting for 42.17% of the total area of the headwaters of the Yangtze River; this was followed by desert, accounting for 16.49%; sand, gobi and bare land accounted for 11.81%; wet- and marshland had the lowest share, accounting for 9.66%, of which stream and rivers, lake, and reservoir and ponds accounted for 5.23%, permanent ice and snow accounted for 2.03%, and shoaly land and swamp accounted for 2.40%. In the headwaters of the Yellow River, grassland was the dominating LULC type as well, which accounted for 79.04% of the total area, with the high-coverage grassland accounting for 27.70%, the medium-coverage grassland accounting for 17.70% and the low-coverage grassland accounting for 33.64%; sand, gobi and bare land accounted for 9.98%; wet- and marshland accounted for 9.32%, of which the stream and rivers, lake, and reservoir and ponds accounted for 4.88%, shoaly land and swamp accounted for 4.44%; forest and shrub accounted for 1.63%; and build-up area had the lowest share, accounting for 0.02% (Figure 4). The LULC types in the headwaters of the Yangtze River and Yellow River were different. While there were only grassland, wet- and marshland, sand, gobi and bare land, and desert in the headwaters of the Yangtze River, the headwaters of the Yellow River, in addition to these LULC types, had forest, shrub and build-up area as well; however, desert was absent in these areas. Further, although grassland was the dominating LULC type in both headwaters of the Yangtze River and Yellow River, the area percentage of grassland in the headwaters of the Yellow River was 17.00% more than in the headwaters of the Yangtze River, especially the high-coverage grassland; and permanent ice and snow were present in the headwaters of the Yangtze River with their area percentage being 2.03%, while there was none in the headwaters of the Yellow River.



(**a**)



(**b**)

Figure 4. LULC types (**a**) and spatial distribution (**b**) in the headwaters of the Yangtze River and Yellow River in 2012.

4.2. The Direction and Magnitude of LULC Change

From the late 1970s to the early 1990s, the main manifestations of LULC change in the headwaters of the Yangtze River were in the form of shrinkage of wet- and marshland, showing a decrease of 2.38 km^2, and desertification, showing an increase of 2.59 km^2. The analysis of the transition matrix revealed that 9.36-, 5.11- and 1.28-km^2 water bodies were converted to shoaly land and swamp, desert and low-coverage grassland, respectively; 2.76 km^2 of desert were transformed to water bodies, and 1.63 km^2 of low-coverage grassland were converted to water bodies.

The main forms of LULC change in the headwaters of the Yellow River were the expansion of sand, gobi and bare land and a decline of grassland coverage. The transition matrix showed that high-coverage grassland primarily converted to medium-coverage grassland resulted in a 447.13-km^2 loss totally; medium-coverage grassland mainly transformed to low-coverage grassland with 295.92 km^2, and low-coverage grassland primarily converted to sand, gobi and bare land with 93.32 km^2, indicating a gain of 74.68 km^2 in sand, gobi and bare land and a decrease of 83.59 km^2 in the grassland area totally (Table 3).

From early 1990s to 2004, expansion of wet- and marshland was the main form of LULC change in the headwaters of the Yangtze River. The transition matrix indicated that the 10.83-km^2 increase in wet- and marshland area mainly resulted from the conversion from desert (6.96 km^2), grassland (2.58 km^2), and sand, gobi and bare land (1.28 km^2). Desert decreased markedly by 7.41 km^2.

In the headwaters of the Yellow River, similar patterns of LULC change were found with the magnitude being more dramatic compared to the prior period. A decline of grassland coverage, shrinkage of wet- and marshland and significant expansion in sand, gobi and bare land were noticed. The grassland experienced a dramatic change with 227.46 km^2 high-coverage grassland, 294.94 km^2 medium-coverage grassland and 766.76 km^2 low-coverage grassland transforming to medium-coverage grassland, low-coverage grassland and sand, gobi and bare land, respectively, and the total grassland area decreased by 660.06 km^2. The wet- and marshland decreased 79.81 km^2 with shoaly land and swamp converting to grassland primarily. The sand, gobi and bare land increased by 740.53 km^2, mainly converted from low-coverage grassland (Table 4).

From 2004 to 2012, LULC change was more dramatic compared to the prior two periods in the headwaters of the Yangtze River. Expansions of grassland and wet- and marshland, and a decrease of sand, gobi and bare land area were the main forms of LULC change, and glacier retreat occurred in this period. The transition matrix showed that, with the sand, gobi and bare land and desert primarily changing to low-coverage grassland and water bodies, shoaly land and swamp changing to grassland and low-coverage grassland changing to water bodies, the grassland increased by 43.45 km^2, wherein the low-coverage grassland increased by 24.73 km^2, and the wet- and marshland increased by 5.09 km^2, wherein the water bodies increased by 23.94 km^2, and the sand, gobi and bare land decreased by 39.76 km^2.

In the headwaters of the Yellow River, an increase of grassland coverage, expansion of wet- and marshland and a decrease of sand, gobi and bare land area were the main LULC change types. With 190.10 km^2 medium-coverage grassland converting to high-coverage grassland, 627.85 km^2 low-coverage grassland converting to medium-coverage grassland and 209.17 km^2 sand, gobi and bare land converting to low-coverage grassland, the grassland coverage increased significantly and the total area increased by 127.51 km^2 and sand, gobi and bare land area decreased markedly by 218.77 km^2. The wet- and marshland increased by 91.27 km^2, mainly converting from low-coverage grassland, wherein the water bodies increased by 163.07 km^2 (Table 5).

In general, during the last 30 years (from the late 1970s to 2012), the examination of LULC changes revealed that, in the headwaters of the Yangtze River, the expansion of grassland and wet- and marshland and the shrinkage of sand, gobi and bare land and desert were the main forms of LULC change, whereas, in the headwaters of the Yellow River, a significant reduction of grassland coverage, shrinkage of wet- and marshland and the consequential expansion of sand, gobi and bare land were noticed.

Table 3. Direction and magnitude of LULC changes from the late 1970s to the early 1990s in the headwaters of the (**A**) Yangtze River and (**B**) Yellow River (unit: km^2).

(A) The headwaters of the Yangtze River

LULC Types	High Coverage Grassland	Medium Coverage Grassland	Low Coverage Grassland	Water Bodies	Permanent Ice and Snow	Shoaly Land and Swamp	Sand, Gobi and Bare Land	Desert	The Late 1970s
high-coverage grassland	1398.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1398.20
medium-coverage grassland	0.00	2442.57	0.00	0.47	0.00	0.00	0.00	0.00	2443.04
low-coverage grassland	0.00	0.00	8162.07	1.63	0.00	0.00	0.00	0.24	8163.94
water bodies	0.00	0.00	1.28	956.95	0.00	9.36	0.85	5.11	973.55
permanent ice and snow	0.00	0.00	0.00	0.00	397.15	0.00	0.00	0.00	397.15
shoaly land and swamp	0.00	0.00	0.00	2.80	0.00	488.61	0.00	0.00	491.41
sand, gobi and bare land	0.00	0.00	0.00	0.00	0.00	0.00	2333.10	0.00	2333.10
desert	0.00	0.00	0.00	2.76	0.00	0.00	0.00	3216.26	3219.02
The early 1990s	1398.20	2442.57	8163.35	964.61	397.15	497.96	2333.95	3221.62	19,419.41

(B) The headwaters of the Yellow River

LULC Types	Forest	Shrub	High Coverage Grassland	Medium Coverage Grassland	Low Coverage Grassland	Water Bodies	Shoaly Land and Swamp	Build-up Area	Sand, Gobi and Bare Land	The Late 1970s
forest	30.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.29
shrub	0.00	687.26	1.50	2.83	0.28	0.00	0.26	0.00	0.00	692.13
high-coverage grassland	0.00	0.00	12,261.27	416.88	25.66	0.00	11.46	0.88	0.04	12,716.19
medium-coverage grassland	0.00	0.00	4.40	7096.47	295.92	0.00	0.18	0.00	2.91	7399.88
low-coverage grassland	0.00	0.00	0.24	7.63	15,038.61	0.06	9.09	1.34	93.32	15,150.28
water bodies	0.00	0.00	0.45	0.00	2.44	2068.57	2.48	0.00	0.00	2073.93
shoaly land and swamp	0.00	0.00	0.31	0.00	4.07	0.00	1990.20	0.00	0.00	1994.58
build-up area	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.73	0.00	7.73
sand, gobi and bare land	0.00	0.00	0.00	0.00	21.59	0.00	0.00	0.00	3851.44	3873.03
The early 1990s	30.29	687.26	12,268.17	7523.81	15,388.56	2068.62	2013.67	9.95	3947.71	43,938.05

Table 4. Direction and magnitude of LULC changes from early 1990s to 2004 in the headwaters of the (**A**) Yangtze River and (**B**) Yellow River (unit: km^2).

(A) The headwaters of the Yangtze River

LULC Types	High Coverage Grassland	Medium Coverage Grassland	Low Coverage Grassland	Water Bodies	Permanent Ice and Snow	Shoaly land and Swamp	Sand, Gobi and Bare Land	Desert	The Early 1990s
high-coverage grassland	1398.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1398.20
medium-coverage grassland	0.00	2442.42	0.00	0.15	0.00	0.00	0.00	0.00	2442.57
low-coverage grassland	0.00	0.00	8160.92	2.43	0.00	0.00	0.00	0.00	8163.35
water bodies	0.00	0.00	0.00	964.61	0.00	0.00	0.00	0.00	964.61
permanent ice and snow	0.00	0.00	0.00	0.00	397.15	0.00	0.00	0.00	397.15
shoaly land and swamp	0.00	0.00	0.00	18.87	0.00	479.10	0.00	0.00	497.96
sand, gobi and bare land	0.00	0.00	0.00	1.28	0.00	0.00	2332.67	0.00	2333.95
desert	0.00	0.00	0.44	6.96	0.00	0.00	0.00	3214.21	3221.62
2004	1398.20	2442.42	8161.36	994.30	397.15	479.10	2332.67	3214.21	19,419.41

(B) The headwaters of the Yellow River

LULC Types	Forest	Shrub	High Coverage Grassland	Medium Coverage Grassland	Low Coverage Grassland	Water Bodies	Shoaly Land and Swamp	Build-up Area	Sand, Gobi and Bare Land	The Early 1990s
forest	30.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.29
shrub	0.00	686.58	0.67	0.00	0.00	0.00	0.00	0.00	0.00	687.26
high-coverage grassland	0.00	0.00	11960.96	227.46	74.71	0.00	4.93	0.10	0.00	12,268.17
medium-coverage grassland	0.00	0.00	0.00	7223.77	294.94	0.39	0.22	0.00	4.50	7523.81
low-coverage grassland	0.00	0.00	0.13	1.87	14,615.70	1.90	1.91	0.32	766.73	15,388.56
water bodies	0.00	0.00	1.32	1.01	12.05	1968.62	84.88	0.00	0.75	2068.62
shoaly land and swamp	0.00	0.00	19.47	17.44	36.59	7.94	1931.70	0.00	0.54	2013.67
build-up area	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.95	0.00	9.95
sand, gobi and bare land	0.00	0.00	0.00	0.00	31.97	0.00	0.00	0.00	3915.74	3947.71
2004	30.29	686.58	11,982.56	7471.55	15,065.96	1978.85	2023.64	10.38	4688.24	43,938.05

Table 5. Direction and magnitude of LULC changes from 2004 to 2012 in the headwaters of the (**A**) Yangtze River and (**B**) Yellow River (unit: km^2).

(A) The headwaters of the Yangtze River

LULC Types	High Coverage Grassland	Medium Coverage Grassland	Low Coverage Grassland	Water Bodies	Permanent Ice and Snow	Shoaly Land and Swamp	Sand, Gobi and Bare Land	Desert	2004
high-coverage grassland	1394.97	2.86	0.19	0.17	0.00	0.00	0.00	0.00	1398.20
medium-coverage grassland	0.18	2441.39	0.78	0.06	0.00	0.00	0.00	0.00	2442.42
low-coverage grassland	0.84	5.32	8138.59	8.64	0.00	0.27	7.70	0.00	8161.36
water bodies	0.00	0.00	0.08	994.19	0.00	0.03	0.00	0.00	994.30
permanent ice and snow	0.00	0.00	0.00	0.00	394.92	0.00	2.23	0.00	397.15
shoaly land and swamp	7.26	3.93	1.79	3.93	0.00	462.19	0.00	0.00	479.10
sand, gobi and bare land	0.02	0.95	43.02	5.70	0.00	0.00	2282.98	0.00	2332.67
desert	0.40	1.19	1.64	5.55	0.00	0.00	0.00	3205.43	3214.21
2012	1403.69	2455.65	8186.09	1018.24	394.92	462.48	2292.91	3205.43	19,419.41

(B) The headwaters of the Yellow River

LULC Types	Forest	Shrub	High Coverage Grassland	Medium Coverage Grassland	Low Coverage Grassland	Water Bodies	Shoaly Land and Swamp	Build-up Area	Sand, Gobi and Bare Land	2004
forest	30.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.29
shrub	0.00	686.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	686.58
high-coverage grassland	0.00	0.00	11,957.12	21.44	1.96	0.39	1.65	0.00	0.00	11,982.56
medium-coverage grassland	0.00	0.00	190.10	7271.07	1.67	7.21	1.50	0.00	0.00	7471.55
low-coverage grassland	0.00	0.00	18.74	627.85	14,329.64	43.27	46.47	0.00	0.00	15,065.96
water bodies	0.00	0.00	0.00	0.27	6.23	1972.29	0.06	0.00	0.00	1978.85
shoaly land and swamp	0.00	0.00	3.31	0.00	8.39	112.78	1899.16	0.00	0.00	2023.64
build-up area	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.38	0.00	10.38
sand, gobi and bare land	0.00	0.00	0.00	0.63	209.17	5.98	2.99	0.00	4469.47	4688.24
2012	30.29	686.58	12,169.27	7921.25	14,557.06	2141.92	1951.83	10.38	4469.47	43,938.05

4.3. Land Use/Cover Change Index

In the past 30 years, the LULC change indexes of the headwaters of the Yangtze River were −0.09%, 0.33% and 0.71%, respectively, while the indexes of the headwaters of the Yellow River were −1.97%, −5.70% and 3.91%, respectively. As can be seen in Figure 5, the magnitude of change in the LULC change index in the headwaters of the Yellow River was more dramatic than in the headwaters of the Yangtze River. From the late 1970s to the early 1990s, the degradation of the macro-ecological situation in the headwaters of the Yellow River was more serious than in the headwaters of the Yangtze River; from the early 1990s to 2004, while the LULC change index in the headwaters of the Yangtze River was positive and the macro-ecological situation started to improve, the degradation in the headwaters of the Yellow River was more severe; from 2004 to 2012, while the macro-ecological situation in both regions showed a certain degree of recovery and melioration, magnitude of improvement in the headwaters of the Yellow River was more evident than that in the headwaters of the Yangtze River.

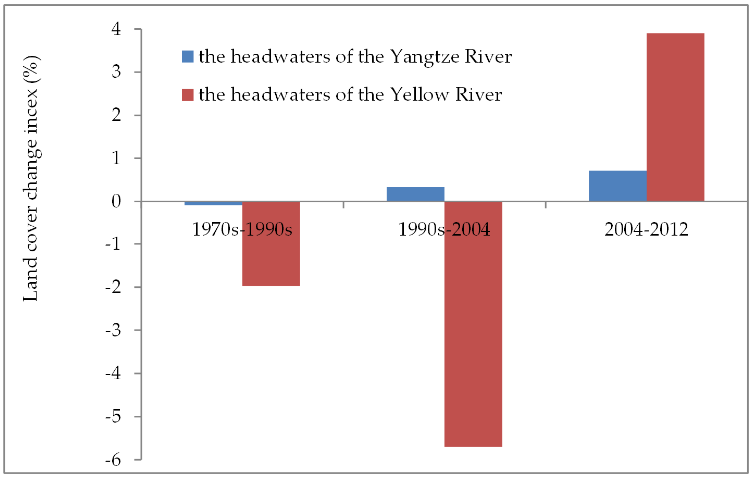


Figure 5. The LULC change index in the headwaters of the Yangtze River and Yellow River.

5. Discussion and Conclusions

5.1. Discussion

The forces driving LULC change can generally be summed up as the natural factors and human activities [36]. Li *et al.* [37] found that, on a ten-year time scale, climate change is the determining factor for vegetation growth, and that human activities can accelerate the process of change. Therefore, we analyzed the driving forces primarily in terms of climate change, the ecological projects, and livestock rearing.

Climate change was analyzed based on the monitoring data from 1975 to 2012 obtained from the Tuotuo River meteorological station in the headwaters of the Yangtze River, and from the Maduo, Dari and Zhongxin meteorological stations in the headwaters of the Yellow River. As shown in Figures 6 and 7 the climate in the headwaters of the Yellow River was warmer and wetter than in the headwaters of the Yangtze River. In the headwaters of the Yangtze River, temperature and precipitation showed an upward trend from the late 1970s to 2012, with the change rates being 0.52 °C/10a and 26.88 mm/10a, respectively. From the late 1970s to the early 1990s, temperature and precipitation showed a non-significant decrease; from the early 1990s to 2012, temperature and precipitation showed a significant upward trend, with the change rates being 0.89 °C/10a and 76.05 mm/10a, respectively; compared to before and after the early 1990s, the average temperature and precipitation increased by 0.99 °C and 43.22 mm, respectively. In the headwaters of the Yellow River, temperature showed a significant upward trend from the late 1970s to 2012, with the change rate being 0.69 °C/10a, while the precipitation levels remained relatively stable; from the late 1970s to 2004, while temperature showed a significant upward trend, with the change rate being 0.59 °C /10a, precipitation showed a non-significant downward trend; from 2004 to 2012, both temperature and precipitation showed a non-significant upward trend; compared to before and after the early 1990s, the average temperature and precipitation increased by 1.456 °C and 443.17 mm, respectively. Warm and wet climatic conditions were considered to have promoted vegetation growth and an increased forage yield in the headwaters of both the Yangtze River and the Yellow River [38].

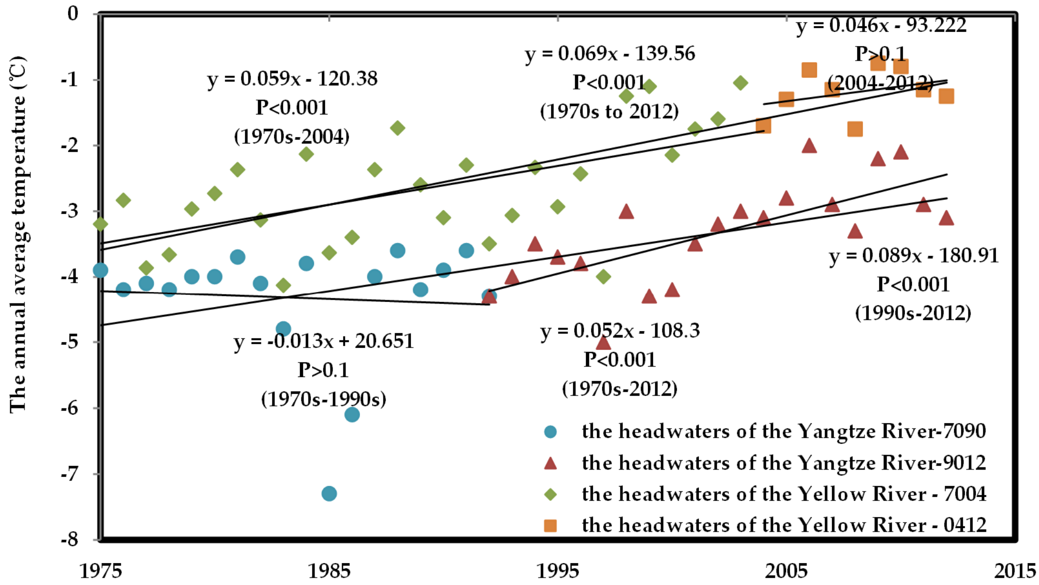


Figure 6. The annual average temperatures in the headwaters of the Yangtze River and Yellow River from 1975 to 2012.

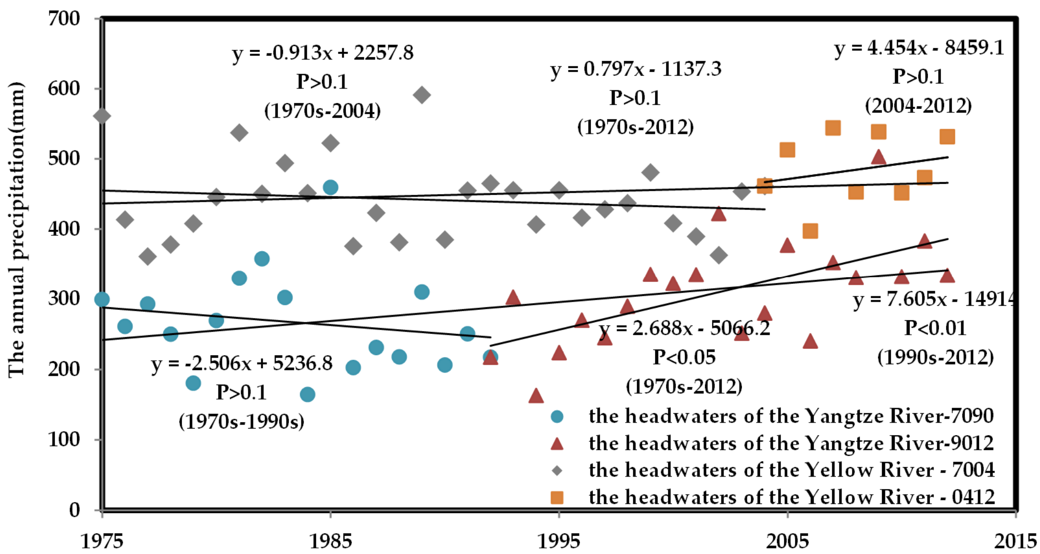


Figure 7. The annual precipitation in the headwaters of the Yangtze River and Yellow River from 1975 to 2012.

Since the implementation of the Livestock-Reduction project in 2003, the number of livestock in the headwaters of the Yellow River (The number of livestock for each county in the region was obtained from statistical data provided by the Qinghai government, and the number of livestock in the headwaters of the Yellow River was represented by statistics data of Banma, Chengduo, Dari, Gande, Maduo, Maqin and Qumalai counties.) has significantly reduced, with a reduction of 30.57% compared to the period before the project (1988–2002) (Figure 8), and the grazing pressure [20] decreased from 3.59 to 1.09. In the county of Tanggulashan, where the headwaters of the Yangtze River are mainly located, the livestock was reduced in total by 4.81 × 10^4 sheep units [39]. The decrease in the grazing pressure would be helpful in the recovery of the grassland.

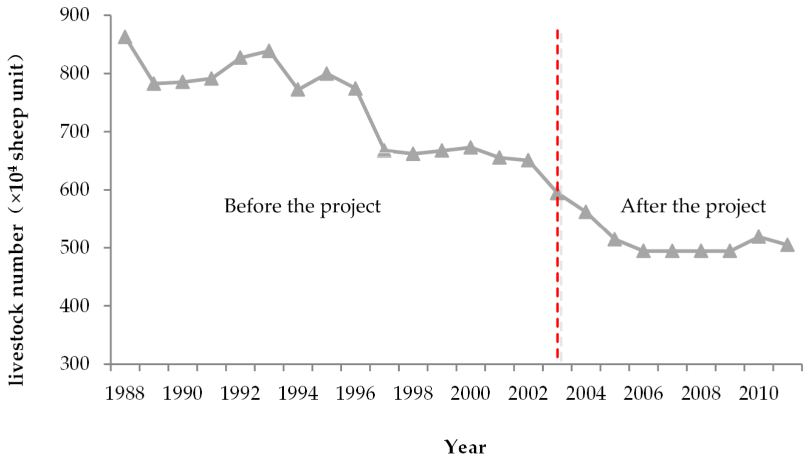


Figure 8. The annual livestock units in the headwaters of the Yellow River from 1988 to 2012.

The implementation of various ecological projects has been playing a key role in LULC change. The Return Grazing Land to Grass project and "black soil beach" management ("black soil beach" means bare soil formed after degradation of alpine meadows [40]) have been helpful in vegetation growth and increasing forage yield; ecological migration [41] and the Livestock-Reduction project have helped reduce the livestock number, which has promoted the increase of grassland coverage; combating desertification has helped promote the sand-fixing capacity of vegetation and inhibit the expansion of the desert; human-induced rainfall has increased the lake and wetland area and the river runoff, mainly in the headwaters of the Yellow River.

In summary, because of the lower elevation and a warm-wet climate, vegetation coverage and the wet- and marshland area in the headwaters of the Yellow River were much greater than those in the headwaters of the Yangtze River. In the headwaters of the Yangtze River, from the late 1970s to early 1990s, both a cold-dry type of climate and excessive grazing pressure caused a shrinkage in wet- and marshland and desertification; after the early 1990s, when the temperature and precipitation clearly started to increase, the LULC changed with an expansion in the wet- and marshland resulting from the conversion of desert. This change continued after 2004 with the melting of glaciers and snow covers, and the positive effects of the projects. In the headwaters of the Yellow River, during the late 1970s to 2004, a warm-dry climate and an excessive grazing pressure caused desertification, a decrease in the grassland coverage and wet- and marshland area; after 2004, an increase in precipitation, a reduced grazing pressure and the implementation of various projects all contributed to the increase of grassland coverage and expansion of wet- and marshland. Because of the constraints of climate and topography, the ecosystem in the headwaters of the Yangtze River is more fragile than in the headwaters of the Yellow River. In addition, the project implementation intensity in the headwaters of the Yangtze River was weaker than in the headwaters of the Yellow River; therefore, the LULC change in the headwaters of the Yangtze River was not as dramatic as in the headwaters of the Yellow River.

The findings of our research showed that the LULC in the Tuotuo River basin changed in a positive way from the early 1990s with expansion of grassland and wet- and marshland area, a result that was different from other research that has considered that the positive change starting from 2004 onward. The reason for this assumption was that their study areas included the entire Yangtze River source region or the TRHR, which would obscure the particularity of the Tuotuo River basin. The Tuotuo River basin, located at the eastern foot of Tanggula Mountains, was widely spread with glaciers and mountains of snow. With the ongoing accelerated warming and glacier retreat, more water will be supplied to the Tuotuo River, which is a glacier-fed river [42]. According to runoff data from the Tuotuo River hydrological stations, during the period of 1975–2011, the annual average runoff was 0.91 billion m^3, showing an upward trend of 0.27 m^3/a; during the period of 1997–2004, the annual average runoff was 1.17 billion m^3, showing an upward trend of 0.52 m^3/a; after 2004, the water supply capacity of the river continuously increased, with the annual average runoff being 1.31 billion m^3, showing an upward trend of 0.91 m^3/a. Compared to the period of 1997–2004, the runoff increased by 12.0% after 2004. According to the monthly data for the period of 1975–2011, the runoff in flood season accounted for 96.8% of the total annual runoff, especially in August. All these data showed that temperature is an important factor influencing the change in the Tuotuo River runoff. Therefore, from the early 1990s, when the temperature started to rise, the LULC in the headwaters of the Yangtze River began to change in a positive way. However, glacier retreat and permafrost thawing owing to a rise in temperature would pose a threat to the balance of the natural ecosystems, which is another serious issue that needs to be solved urgently.

The majority of the literature suggests that LULC change would introduce substantial change to the ecosystem. Research in Dhaka revealed that unplanned and rapid urbanization had a possibility of inducing many environmental adversities in the near future, such as serious urban flooding, highly fragmented landscape, a decline of landscape diversity and a decrease of green space [33,43,44]. Deforestation would cause an increase in annual runoff and a decrease in annual evapotranspiration in Southern China [7]. The reduction of forest and expansion of urban and build-up area has influenced the carbon balance in North Korea [45]. A substantial (20%–50%) decline across ecosystem services as a result of land-cover change in the Little Karoo was also reported [32]. In the TRHR, many researchers have conducted studies on the LULC and the ecosystem and their services as well. During 1995 to 2000, land use contributed about 58% to the water supply decrease because of the intense human activities in the Yellow River Source Area, and contributed about 61% to the water supply increase from 2005 to 2008 with improved vegetation coverage conditions and the water retention ability after the implementation of the ecological projects [46]. Grassland degradation resulted in great carbon emissions in the TRHR before 2004, but grassland restoration after 2004 sequestered carbon 4.4 times more than that before 2004 [25].

Although the LULC has changed in a positive way, we are still a long way from achieving a full recovery of the ecosystem in the headwaters of the Yangtze River and Yellow River. The vegetation coverage is increasing, but it is not obvious that the community structure has improved [20]: Overgrazing is still severe, which is one of the main causes of grassland deterioration [47]; an increase in precipitation could promote vegetation growth, but the erosive force of rainfall has also been strengthened [38]; and, with further increases in temperature, the climate could gradually show a warming and drying trend, which would inhibit the growth of vegetation [24]. Further, while the water supply capacity has clearly increased, besides the increase in precipitation, the melting of glaciers and permafrost due to the rising temperatures has also increased the runoff, which is unsustainable and could threaten the local ecosystem balance. Therefore, the ecosystem protection in the second stage of the ecological projects should be sustainable and spatially targeted to maximize the benefits; meanwhile, the philosophy of social engineering should also be employed [40].

It must be noted that, due to the limitation of expert knowledge, similar spectral characteristics of different LULC types [44], blurred texture feature, data resolution and the complexity of classification, the possible inaccuracy is difficult to subdue, especially for the MSS images because of its coarse spatial resolution that leads to spectral mixing of different land covers [17]. Given those limitations, we have tried to minimize the inaccuracy by constructing the LULC datasets of the late 1970s, the early 1990s and 2012 based on the LULC dataset of 2004 and change information extracting directly from the comparison between RS images in the late 1970s, the early 1990s and 2012, and the RS images in 2004. During the classification process, the expert knowledge, the geographic condition and other auxiliary data like vegetation maps, grassland maps and topographic maps were fully obtained. Meanwhile, the

LULC dataset of 2004 underwent careful and rigorous visual inspection, and were compared with the original images and field investigation data. The overall accuracy was 95.66%, which can guarantee the accuracy of LULC datasets of other time periods in a relatively high level. Another thing that should be noted is that the gradation result of the ecological level for every LULC type in this research (Table 2) cannot be popularized at the national scale. For example, in food production areas, farmland, with a high supply service, should be graded with the highest ecological level. Therefore, the definition of the ecological levels of different LULC types in this research is only suited for the TRHR. When popularizing these to other areas, researchers should adjust or consider other LULC types according to the main ecological services of the specific research areas.

5.2. Conclusions

Based on remote sensing images in the late 1970s, the early 1990s, 2004 and 2012, the LULC datasets in the headwaters of the Yangtze River and Yellow River were developed, and LULC and macro-ecological situations and changes were contrastively analyzed by applying the transition matrix and LULC change index. The main conclusions can be summarized as follows:

(1) While the dominant LULC type was grassland in the headwaters of both the Yangtze River and Yellow River, the area percentage of the grassland in the headwaters of the Yellow River was 17.00% more than in the headwaters of the Yangtze River, especially the high-coverage grassland; in addition, permanent ice and snow were found only in the headwaters of the Yangtze River, with their percentage being 2.03%.

(2) During the past 30 years, in the headwaters of the Yangtze River, the grassland and wet- and marshland area increased at the expense of sand, gobi and bare land and desert; in the headwaters of the Yellow River, significant reduction of grassland coverage, shrinkage of wet- and marshland and the consequential expansion of sand, gobi and bare land were noticed, and the change magnitude was more dramatic overall. From the late 1970s to the early 1990s, shrinkage of wet- and marshland and desertification were the main LULC change types in the headwaters of the Yangtze River, while an expansion of sand, gobi and bare land and a decline in grassland coverage were the main LULC change types in the headwaters of the Yellow River. From the early 1990s to 2004, desert changing to wet- and marshland was the main LULC change type in the headwaters of the Yangtze River, while a further grassland deterioration, wet- and marshland shrinkage and significant expansion in sand, gobi and bare land were noticed in the headwaters of the Yellow River. From 2004 to 2012, the sand, gobi and bare land and desert changing to wet- and marshland and grassland were the main LULC change types in the headwaters of the Yangtze River; in the headwaters of the Yellow River, an increase in grassland coverage, expansion of the wet- and marshland and a decrease in the sand, gobi and bare land area were the main LULC change types.

(3) According to the LULC change index, during the past 30 years, the macro-ecological situation in the headwaters of the Yangtze River has experienced a process of degeneration, slight melioration, and continuous melioration, in that order; while the headwaters of the Yellow River has experienced a process of degeneration, obvious degeneration, and slight melioration, in that order. In addition, the change magnitude in the headwaters of the Yellow River has been more dramatic than in the headwaters of the Yangtze River.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

TRHR	the Three-River Headwaters Region
LULC	Land use and land cover

References

1. Liu, J.; Kuang, W.; Zhang, Z.; Xu, X.; Qin, Y.; Ning, J.; Zhou, W.; Zhang, S.; Li, R.; Yan, C.; *et al*. Spatiotemporal characteristics, patterns, and causes of land-use changes in China since the late 1980s. *J. Geogr. Sci.* **2014**, *24*, 195–210. [CrossRef]
2. Gascoigne, W.R.; Hoag, D.; Koontz, L.; Tangen, B.A.; Shaffer, T.L.; Gleason, R.A. Valuing ecosystem and economic services across land-use scenarios in the Prairie Pothole Region of the Dakotas, USA. *Ecol. Econ.* **2011**, *70*, 1715–1725. [CrossRef]
3. Wang, W.; Guo, H.; Chuai, X.; Dai, C.; Lai, L.; Zhang, M. The impact of land use change on the temporospatial variations of ecosystems services value in China and an optimized land use solution. *Environ. Sci. Policy* **2014**, *44*, 62–72. [CrossRef]
4. Geneletti, D. Assessing the impact of alternative land-use zoning policies on future ecosystem services. *Environ. Impact Assess. Rev.* **2013**, *40*, 25–35. [CrossRef]
5. Liu, J.; Daily, G.C.; Ehrlich, P.R.; Luck, G.W. Effects of household dynamics on resource consumption and biodiversity. *Nature* **2003**, *421*, 530–533. [CrossRef] [PubMed]
6. Dewan, A.M.; Yamaguchi, Y.; Ziaur Rahman, M. Dynamics of land use/cover changes and the analysis of landscape fragmentation in Dhaka metropolitan, Bangladesh. *GeoJournal* **2012**, *77*, 315–330. [CrossRef]
7. Wang, K.; Zhang, Q.; Chen, Y.D.; Singh, V.P. Effects of land-use/cover change on hydrological processes using a gis/rs-based integrated hydrological model: Case study of the East River, China. *Hydrol. Sci. J.* **2015**, *60*, 1724–1738. [CrossRef]
8. Dewan, A.M.; Yamaguchi, Y. Land use and land cover change in greater Dhaka, Bangladesh: Using remote sensing to promote sustainable urbanization. *Appl. Geogr.* **2009**, *29*, 390–401. [CrossRef]
9. Jiang, Y.; Fu, P.; Weng, Q. Assessing the impacts of urbanization-associated land use/cover change on land surface temperature and surface moisture: A case study in the midwestern United States. *Remote Sens.* **2015**, *7*, 4880–4898. [CrossRef]
10. Ge, X.; Dong, K.; Luloff, A.E.; Wang, L.; Xiao, J.; Wang, S.; Wang, Q. Correlation between landscape fragmentation and sandy desertification: A case study in Horqin sandy land, China. *Environ. Monit. Assess.* **2016**, *188*. [CrossRef] [PubMed]
11. Ge, X.; Dong, K.; Luloff, A.E.; Wang, L.; Xiao, J. Impact of land use intensity on sandy desertification: An evidence from Horqin sandy land, China. *Ecol. Indic.* **2016**, *61*, 346–358. [CrossRef]
12. Clement, M.T.; Chi, G.; Ho, H.C. Urbanization and land-use change: A human ecology of deforestation across the United States, 2001–2006. *Soc. Inquiry* **2015**, *85*, 628–653. [CrossRef]
13. Mooney, H.A.; Duraiappah, A.; Larigauderie, A. Evolution of natural and social science interactions in global change research programs. *Proc. Natl. Acad. Sci. USA* **2013**, *110*, 3665–3672. [CrossRef] [PubMed]
14. Abd El-Kawy, O.R.; Rød, J.K.; Ismail, H.A.; Suliman, A.S. Land use and land cover change detection in the western Nile Delta of Egypt using remote sensing data. *Appl. Geogr.* **2011**, *31*, 483–494. [CrossRef]
15. Yang, X.Y.; Chen, L.G.; Li, Y.K.; Xi, W.J.; Chen, L.Q. Rule-based land use/land cover classification in coastal areas using seasonal remote sensing imagery: A case study from Lianyungang City, China. *Environ. Monit. Assess.* **2015**, *187*. [CrossRef] [PubMed]
16. Shalaby, A.; Tateishi, R. Remote sensing and GIS for mapping and monitoring land cover and land-use changes in the northwestern coastal zone of Egypt. *Appl. Geogr.* **2007**, *27*, 28–41. [CrossRef]
17. Yang, X.; Lo, C. Using a time series of satellite imagery to detect land use and land cover changes in the Atlanta, Georgia metropolitan area. *Int. J. Remote Sens.* **2002**, *23*, 1775–1798. [CrossRef]
18. Alphan, H.; Doygun, H.; Unlukaplan, Y.I. Post-classification comparison of land cover using multitemporal landsat and aster imagery: The case of Kahramanmaras, Turkey. *Environ. Monit. Assess.* **2009**, *151*, 327–336. [CrossRef]

19. Yuan, F.; Sawaya, K.E.; Loeffelholz, B.; Bauer, M.E. Land cover classification and change analysis of the Twin Cities (Minnesota) metropolitan area by multi-temporal Landsat remote sensing. *Remote Sens. Environ.* **2005**, *98*, 317–328. [CrossRef]
20. Fan, J.W.; Shao, Q.Q.; Liu, J.Y.; Wang, J.B.; Harris, W.; Chen, Z.Q.; Zhong, H.P.; Xu, X.L.; Liu, R.G. Assessment of effects of climate change and grazing activity on grassland yield in the Three Rivers Headwaters Region of Qinghai-Tibet plateau, China. *Environ. Monit. Assess.* **2010**, *170*, 571–584. [CrossRef] [PubMed]
21. Xu, X.L.; Liu, J.Y.; Shao, Q.Q.; Fan, J.W. The dynamic changes of ecosystem spatial pattern and structure in the Three-River Headwaters region in Qinghai Province during recent 30 years. *Geogr. Res.* **2008**, *27*, 829–838.
22. Shao, Q.Q.; Zhao, Z.P.; Liu, J.Y.; Fan, J.W. The characteristics of land cover and macroscopical ecology changes in the source region of three rivers on Qinghai Tibet Plateau during the last 30 years. *Geogr. Res.* **2010**, *29*, 1439–1451.
23. Shao, Q.Q.; Fan, J.W. *Integrated Monitoring and Evaluation of Ecosystem in the Three Rivers Headwaters Region*; Science Press: Beijing, China, 2012.
24. Liu, X.F.; Zhang, J.S.; Zhu, X.F.; Pan, Y.Z.; Liu, Y.X.; Zhang, D.H.; Lin, Z.H. Spatiotemporal changes in vegetation coverage and its driving factors in the three-river headwaters region during 2000–2011. *J. Geogr. Sci.* **2014**, *24*, 288–302. [CrossRef]
25. Huang, L.; Xu, X.L.; Shao, Q.Q.; Liu, J.Y. Improving carbon mitigation potential through grassland ecosystem restoration under climatic change in northeastern Tibetan plateau. *Adv. Meteorol.* **2014**, *2014*. [CrossRef]
26. Tong, L.G.; Xu, X.L.; Fu, Y.; Li, S. Wetland changes and their responses to climate change in the "Three-river Headwaters" region of China since the 1990s. *Energies* **2014**, *7*, 2515–2534. [CrossRef]
27. Ding, Y.J.; Liu, S.Y.; Chen, R.S.; Wang, G.X.; Shen, Y.P.; Wang, J.; Xie, C.W.; Zhang, S.Q. Exploration of eco-environment range in the source regions of the Yangtze and Yellow rivers. *J. Geogr. Sci.* **2003**, *58*, 519–526.
28. Liu, J.Y.; Liu, M.L.; Tian, H.Q.; Zhuang, D.F.; Zhang, Z.X.; Zhang, W.; Tang, X.M.; Deng, X.Z. Spatial and temporal patterns of China's cropland during 1990–2000: An analysis based on landsat TM data. *Remote Sens. Environ.* **2005**, *98*, 442–456. [CrossRef]
29. Liu, J.Y.; Zhang, Z.X.; Zhuang, D.F. *Research on the Remote Sensing Information on Land Use Change in 1990s, China*; Science Press: Beijing, China, 2005.
30. Nazeer, M.; Nichol, J.E.; Yung, Y.-K. Evaluation of atmospheric correction models and landsat surface reflectance product in an urban coastal environment. *Int. J. Remote Sens.* **2014**, *35*, 6271–6291. [CrossRef]
31. Gilmore, S.; Saleem, A.; Dewan, A.M. Effectiveness of DOS (Dark-Object Subtraction) Method and Water Index Techniques to Map Wetlands in a Rapidly Urbanizing Megacity with Landsat 8 Data. Available online: http://ceur-ws.org/Vol-1323/paper41.pdf (accessed on 22 February 2016).
32. Reyers, B.; O'Farrell, P.J.; Cowling, R.M.; Egoh, B.N.; le Maitre, D.C.; Vlok, J.H.J. Ecosystem services, land-cover change, and stakeholders: Finding a sustainable foothold for a semiarid biodiversity hotspot. *Ecol. Soc.* **2009**, *14*, 23–38.
33. Dewan, A.M.; Humayun Kabir, M.; Nahar, K.; Ziaur Rahman, M. Urbanisation and environmental degradation in Dhaka metropolitan area of Bangladesh. *Int. J. Evriron. Sustain. Dev.* **2012**, *11*, 118–147. [CrossRef]
34. Liu, M.C.; Li, D.Q.; Wen, Y.M.; Luan, X.F. The ecological function analysis and evaluation of ecosystem in Sanjiangyuan region. *Acta Sci. Circumst.* **2005**, *25*, 1280–1286.
35. Lai, M.; Wu, S.H.; Dai, E.F.; Yin, Y.H.; Pan, T.; Zhao, D.S. Dynamic Valuation on Ecosystem Services to Ecological Construction in the Three-River Headwaters Nature Reserve, China. *J. Mt. Sci.* **2013**, *31*, 8–17.
36. Wang, G.X.; Guo, X.Y.; Cheng, G.D. Dynamic variations of landscape pattern and the landscape ecological functions in the source area of the Yellow river. *Acta Ecol. Sin.* **2002**, *22*, 1587–1598.
37. Li, H.X.; Liu, G.H.; Fu, B.J. Response of vegetation to climate change and human activity based on NDVI in the Three-River Headwaters region. *Acta Ecol. Sin.* **2011**, *31*, 5495–5504.
38. Jiang, C.; Zhang, L. Climate change and its impact on the eco-environment of the Three-rivers Headwater Region on the Tibetan plateau, China. *Int. J. Environ. Res. Public Health* **2015**, *12*, 12057–12081. [CrossRef] [PubMed]
39. Ma, S.J. Analysis of ecosystem protection and construction projects implemented in Three-River Headwaters region—A case study in Tanggulashan Town of Geermu City. *Pratacult. Sci.* **2010**, *27*, 161–168.
40. Fang, Y.P. Managing the Three-Rivers headwater region, China: From ecological engineering to social engineering. *Ambio* **2013**, *42*, 566–576. [CrossRef] [PubMed]

41. Mao, X.F.; Wei, X.Y.; Xia, J.X. Evaluation of ecological migrants' adaptation to their new living area in Three-river Headwater wetlands, China. *Procedia Environ. Sci.* **2012**, *13*, 1346–1353. [CrossRef]
42. Zhang, Y.; Liu, S.Y.; Xu, J.L.; Shangguan, D.H. Glacier change and glacier runoff variation in the Tuotuo river basin, the source region of Yangtze River in western China. *Environ. Geol.* **2008**, *56*, 59–68. [CrossRef]
43. Byomkesh, T.; Nakagoshi, N.; Dewan, A.M. Urbanization and green space dynamics in greater Dhaka, Bangladesh. *Landsc. Ecol. Eng.* **2011**, *8*, 45–58. [CrossRef]
44. Dewan, A.M.; Yamaguchi, Y. Using remote sensing and gis to detect and monitor land use and land cover change in Dhaka metropolitan of Bangladesh during 1960–2005. *Environ. Monit. Assess.* **2009**, *150*, 237–249. [CrossRef] [PubMed]
45. Cui, G.; Lee, W.-K.; Kim, D.; Lee, E.J.; Kwak, H.; Choi, H.-A.; Kwak, D.-A.; Jeon, S.; Jeon, S.; Zhu, W. Estimation of forest carbon budget from land cover change in south and north Korea between 1981 and 2010. *J. Plant Biol.* **2014**, *57*, 225–238. [CrossRef]
46. Pan, T.; Wu, S.; Liu, Y. Relative contributions of land use and climate change to water supply variations over yellow river source area in Tibetan plateau during the past three decades. *PLoS ONE* **2015**, *10*, e0123793. [CrossRef] [PubMed]
47. Zhang, J.P.; Zhang, L.B.; Liu, W.L.; Qi, Y.; Wo, X. Livestock-carrying capacity and overgrazing status of alpine grassland in the Three-River headwaters region, China. *J. Geogr. Sci.* **2014**, *24*, 303–312. [CrossRef]