

Article

The Ecological and Social Effects of Cropland Expansion in the Hehuang Valley during the Ming and Qing Dynasties

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Abstract: In this paper, we strive to show that the protection of the ecological environment of the Yellow River can impact regional sustainable development and human society. Based on GIS and historical documents, we selected 1640 AD in the late Ming Dynasty and 1726, 1746, and 1856 AD in the early and middle Qing Dynasty as time sections to reconstruct the distributions of cropland and vegetation in the Hehuang valley. Our results showed that the cropland in the Ming Dynasty was mainly distributed in the valley of Saini; during the early and mid-Qing Dynasty, the cropland reclamation broke the boundary of the Great Wall. Furthermore, replacing vegetation with cropland resulted in the rapid decline of water conservation capacity in the medium and high mountain areas. The decline of water conservation capacity significantly contributed to the frequent occurrence of natural disasters, such as drought, flood, water erosion, and sand pressure, which led to decreased cropland output. By the mid-Qing Dynasty, the cropland area had saturated while the population was still growing, and the grain yield could not meet the demands of the expanding population. Due to both natural and social factors, two social upheavals occurred in the late Qing Dynasty, which significantly affected the development of the regional social economy. Therefore, the destruction of the ecological environment and the reduction of water conservation capacity became an important driving force for the destruction of sustainable regional development.

Keywords: hehuang valley; cropland; water conservation; social upheaval



Citation: Hou, Z.; Lancuo, Z.; Hou, G. The Ecological and Social Effects of Cropland Expansion in the Hehuang Valley during the Ming and Qing Dynasties. *Land* **2022**, *11*, 2143. <https://doi.org/10.3390/land11122143>

Academic Editors: Minmin Ma, Xianrong Cao and Guanghui Dong

Received: 23 October 2022

Accepted: 23 November 2022

Published: 28 November 2022

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1. Introduction

The relationship between the development of human societies and their living environments has been discussed intensively in recent decades. Understanding the patterns and mechanisms of human–environment interaction is valuable to cope with rapidly changing environments in the modern world [1]. In September 2019, Chinese President Xi Jinping delivered a speech on ecological protection and high-quality development of the Yellow River basin [2], which again drew academic attention to the protection of the ecological environment of the Yellow River basin in China [3]. The Yellow River is the mother river of the Chinese nation, as it runs through 9 of the 34 provinces in China. Moreover, it flows through the Loess Plateau, and its basin has been highly exploited throughout history, thus intensifying soil erosion and resulting in a sharp increase in sediment concentration [4,5]. Overall, the Yellow River is not only the mother river of the Chinese nation but also a disastrous river [6,7].

The Yellow River basin is an essential ecological barrier to China, and it is also one of the most densely populated areas and a vital economic belt. Half of the runoff of the Yellow River comes from the Qinghai–Tibet Plateau, the upper reaches of the Yellow River. Therefore, the

ecological and environmental condition of the Qinghai–Tibet Plateau is very important for the maintenance of the entire ecological function of the Yellow River basin [8].

The Huangshui River is an important tributary of the upper reaches of the Yellow River; historically, there were several environmental problems, such as a degraded water conservation capacity, a fragile ecological environment, frequent floods, severe water pollution, and soil erosion. Therefore, studying the relationship between human activities and the ecological environment in the upper reaches of the Yellow River during the historical time is of particular significance to the current ecological and environmental protection and high-quality development of the Yellow River Basin. In this paper, we studied the environmental impacts of the exploitation of the Hehuang valley in history and the subsequent social alterations caused by these environmental impacts.

2. Study Areas

2.1. General Geographical Situation

The research scope of this paper is the Hehuang valley, which includes the Yellow River in Qinghai Province and the Huangshui River valleys. From north to south are Lenglongling, Datong River valley, Dabanshan, Huangshui River valley, Lajishan, and Yellow River valleys. The terrain has a prominent characteristic of a mountain-valley alternate arrangement. The valleys are broad, the terrace is developed, and the areas account for 75% of the Hehuang valley, with altitudes ranging from 1650 m to 2400 m. It is suitable for agricultural development. In terms of administrative areas, the Hehuang valley includes counties and cities of Xining, Datong, Huangzhong, Huangyuan, Menyuan, Huzhu, Pingan, Ledu, Minhe, Xunhua, Hualong, Tongren, Jianzha, and Guide (all within Qinghai Province of China). The study area is about 43,600 km² in total, with a significant altitude drop (1650–5200 m). This area has a plateau temperate semi-arid climate. It is categorized as a semi-arid to arid area, with an average annual temperature of 3–8 °C and annual precipitation of 250–520 mm. The main stream of the Yellow River runs through the whole area from west to east. It develops many major rivers, such as the Huangshui River and the Datong River, respectively, primary and secondary tributaries of the Yellow River (Figure 1).

The vegetation (soil) type is dominated by temperate steppe (soil). Due to the significant difference in altitude and variation in topography, the vertical zonality of vegetation in this area is prominent. The terraces of primary and secondary tributaries with altitudes lower than 2400 m are extensively reclaimed for cropland, where crops such as wheat, broad beans, and peas are cultivated, accompanied by trees such as poplar, willow, and elm. The soil is mainly cropland soil. The small undulating medium mountain area has an altitude of 2200–2400 m, and the vegetation type is dominated by temperate clumped dwarf grass and semi-shrub steppe, with mainly chestnut soil. The middle undulating medium mountain area has an altitude of 2400–2900 m, and the vegetation type is mainly temperate clumped grass steppe with sierozem soil. The large undulating high mountain area has an altitude of 2900–3800 m, and the vegetation type is mainly alpine shrubs like *potentilla fruticosa*, *salix oritrepha*, and *azalea*, with mainly alpine shrub meadow soil. In areas with an altitude of >3800 m, the vegetation type is dominated by alpine meadows, and the main soil is meadow soil [9,10]. In general, the terrace of the primary and secondary tributaries had been wholly replaced by croplands. However, some natural vegetation and vertical zonality have been reserved due to human interference in these areas (Figure 2).

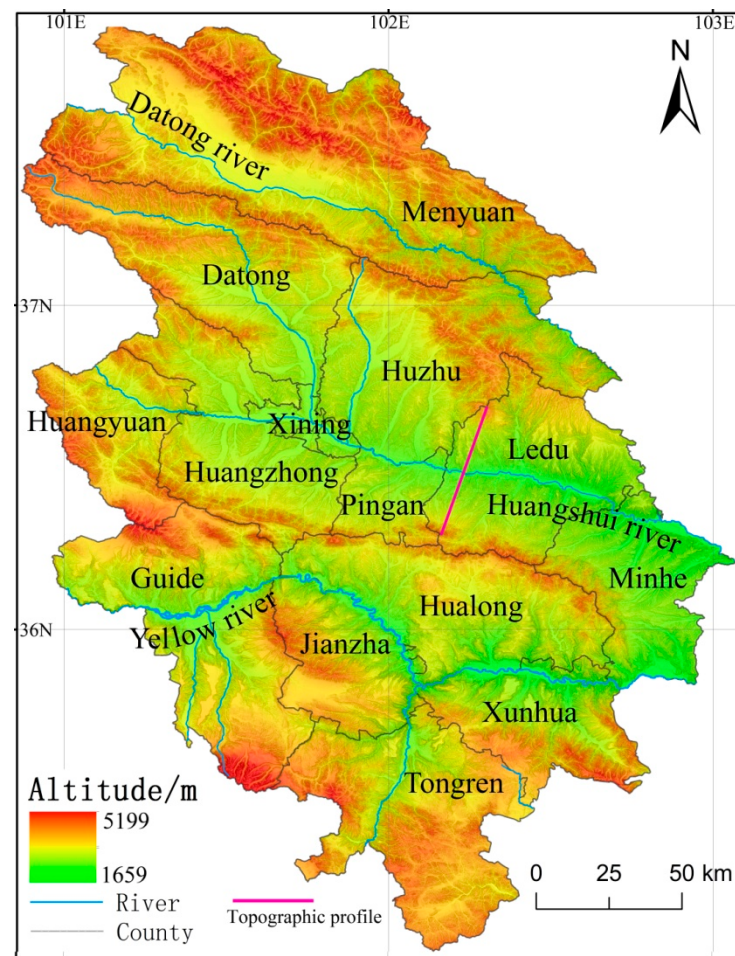


Figure 1. Topography and administrative division of the Hehuang valley.

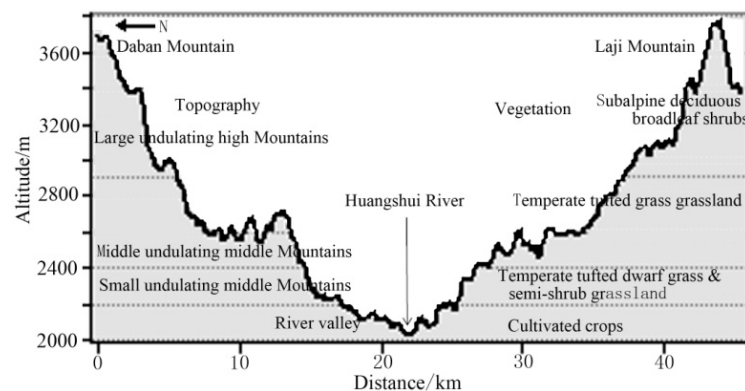


Figure 2. Topographic section and vertical zonation distribution of vegetation on Hehuang valley (corresponding to the topographic section line in Figure 1).

The study area is one of the areas with relatively superior hydrothermal conditions in the Qinghai–Tibet Plateau. Although this area accounts for 5% of the Qinghai Province, it makes up 72.77% of the population and 60% of the cropland in Qinghai Province. The cropland area is 4140 km², while the planting industry accounts for 80% of the total industry in Qinghai Province (Qinghai Provincial Bureau of Statistics, 2016). Therefore, this area has the densest population, towns, and economic activities in the Qinghai–Tibet Plateau (Qinghai Province and Tibet province); it is also one of the areas with the highest utilization rate of agricultural land and economically developed area.

2.2. The Evolution of the Population and Agriculture in the Hehuang Valley during the Ming and Qing Dynasties

As shown in (Table 1), from the early Ming Dynasty (1368–1373 AD), the government set up Xining Wei (a local administrative organization in Ming Dynasty, which is called Xining city today) in the Hehuang valley and recruited soldiers to reclaim the land. According to The New Survey of the Xining Prefecture, 15,854 people were recruited to reclaim cropland. By the middle of the Ming Dynasty (1522–1566 AD), the number of people involved in cropland reclaiming increased to 45,613. Moreover, the cropland area became about 210 km² (data obtained by converting the measurement of cropland in the original literature into km²). In 1578 AD, the number of people involved in cropland reclamation was 38,892, and the cropland area reached 390 km². By the end of the Ming Dynasty, the number of people involved had yet to be counted, while the cropland area had reached 446 km². The growth of the population led to the expansion of cropland. Therefore, the population of the late Ming Dynasty increased considerably compared with that of the early period. In the Ming Dynasty, the cropland in the Hehuang area was mainly distributed in the river valleys between Huangshui and Yellow Rivers and concentrated in the Huangshui valley in the east of Huangyuan, which was most richly irrigated.

The population of Xining Wei in the early Qing Dynasty (1645 AD) was 96,266, consistent with the population of the late Ming Dynasty (the late Ming Dynasty and the early Qing Dynasty were linked together). By 1725 AD, Xining Wei was changed to Xining Prefecture, a local administrative organization under the jurisdiction of the past Xining County, Nianbo County, and Datong Wei, with the addition of Guide sub-prefecture and Xunhua. Until the Qing Dynasty, Xining County included today's Xining city, Huangzhong County, Pingan County, and Huangyuan County. Nianbo County included Ledu County, Minhe County, and some areas of Hualong County. Datong Wei included Datong county and Menyuan County. Guide Ting included Guide county and Jianzha County, and the Xunhua Ting included Xunhua County and Tongren County. These above areas showed complete consistency with the area studied in this paper [11].

Table 1. Literature records of population and cropland during the Ming and Qing Dynasties (1368–1856 AD).

The Dating of China	Calendar Year/AD	Number Of Population/People	The Dating of China	Calendar Year/AD	Registered Cropland Area/km ²
Ming Dynasty, Hongwu	1368–1394	15,848	Ming Dynasty, Yongle	1413	135
Ming Dynasty, Yongle	1403–1424	12,092	Ming Dynasty, Zhengtong 3rd	1438	184
Ming Dynasty, Jiajing	1522–1566	46,988	Ming Dynasty, Jiajing 29th	1550	210
Ming Dynasty, Wan Li 6th	1578	38,892	Ming Dynasty, Wan Li 12th	1584	391
Qing Dynasty, Shunzhi 2nd	1645	109,490	The end of Ming Dynasty	1640	446
Qing Dynasty, Qianlong 11th	1746	245,735	Qing Dynasty, Kangxi 57th	1718	461
Qing Dynasty, Jiaqing 25th	1820	208,603	Qing Dynasty, Yongzheng 4th	1726	1427
Qing Dynasty, Xianfeng 3th	1853	874,418	Qing Dynasty, Qianlong 11th	1746	2329.7
Qing Dynasty, Guangxu 34th	1908	361,255	Qing Dynasty, Xianfeng 6th	1856	3335
Qing Dynasty, Xuantong 1st	1909	367,131	Republic of China 24th	1936	1234.8

Note: the data is from [12–15]. The way of dating is: Ming Dynasty, Hongwu, in which Ming represents the dynasty, Hongwu represents the reign title, and if it has a number in the dating, it represents the year of the ruler's reign; for example, Qing Dynasty, Yongzheng 4th, which represents the fourth year of reign of Yongzheng in the Qing Dynasty.

During the Qing Dynasty, there was an increase in the population of the Hehuang area that had been influenced by both higher social stability and a different reclamation policy from that of the Ming Dynasty. For example, the government of the Qing Dynasty encouraged people to reclaim cropland. After three years of reclamation, the cropland could “forever serve the people” and achieved the goal of “gathering people instead of developing an army”. By 1746 AD, the population doubled and reached 245,735. In the mid-Qing Dynasty (1853 AD), the population reached 874,418. In the early Qing Dynasty (1718 AD), the cropland area was only 461 km². By 1726 AD, it exceeded 1000 km² and reached the historically highest reclamation area during 1850–1861 AD, which is about 3300 km². However, since then, the population and cropland have declined significantly. In the late Qing Dynasty (1908 AD), it decreased from over 513,100 people to 361,255, with a decreasing rate of 58.7%. This sharp decrease in population incurs a question about what happened during this period [16]. It should be noted that historical documents only recorded some years of population and cropland area but need a more specific description of cropland distribution. Thus, we need to reconstruct the spatial distribution of croplands in the past based on historical documents and geographical factors.

3. Data and methods

3.1. Data

The data in this paper are mainly from the following sources: the DEM data of 90 m × 90 m spatial resolution in the research area as provided by the International Scientific and Technical Data Mirror Site, Computer Network Information Center, Chinese Academy of Sciences (<http://www.gscloud.cn>, accessed on 20 April 2020); the slope was obtained through the surface analysis function of ArcGIS and based on the DEM data; the annual average precipitation data of 1 km raster in China (1971–2000) was obtained from the website of Resource Discipline Innovation Platform (<http://www.data.ac.cn/>, accessed on 18 June 2020); 1 km monthly average temperature and precipitation in China (1971–2000) were obtained from the Science and Technology Resource Service System of Chinese National Ecosystem Research Network (<http://www.cnern.org.cn/>, accessed on 25 February 2020) and literature [17]; vegetation data were obtained from the Data Center of Resources and Environment Science, Chinese Academy of Sciences on the spatial distribution data of 1 million vegetation types in China (<https://www.resdc.cn>, accessed on 6 April 2020).

3.2. Methods

3.2.1. Reconstruction of Cropland during the Ming and Qing Dynasties (1368–1908 AD)

In order to reconstruct cropland during the Ming Dynasty, we took the following steps. First, we determined the constraints of cropland reconstruction. The slope was a significant factor in cropland. Generally, the cropland slope was divided into five grades: $\leq 2^\circ$, $2^\circ \sim 6^\circ$, $6^\circ \sim 15^\circ$, $15^\circ \sim 25^\circ$, and $> 25^\circ$. A cropland slope of $\leq 2^\circ$ indicates no soil erosion. By analogy, it is, therefore, appropriate to assume that a slope $> 25^\circ$ would be unsuitable for cropland use. According to the historical literature, the cropland distribution was mainly within the river valleys (Huangshui and Yellow River valleys) at low altitudes with favorable hydrothermal conditions. The 1–2 terraces of the river valley had relatively flat characteristics and therefore flourished in agricultural development. The Ming Dynasty took the Great Wall as a boundary and divided the land into Sainei (the area to the south and east of the Great Wall) and Saiwai (the area to the west and north of the Great Wall). Thus, the areas discussed above were part of Sainei. Accordingly, we can set up the constraints of cropland reconstruction in the Ming Dynasty:

1. Regional conditions of the reconstructing area: the above-stated areas we redistributed in Sainei to the south and east of the Great Wall, and the data concerning the Great Wall of the Ming Dynasty were provided by many scholars [18];
2. Distance condition: the settlement point in the Ming dynasty was within a 5-km buffer zone, and the data on the settlement point in other scholars' publications were cited [19];

3. Slope condition: slope $<6^\circ$;
4. Water source condition: within a 5 km buffer zone from the river;
5. The literature records: the cropland area in the late Ming dynasty was about 446 km² [20].

The second step was to process the data according to the constraints. Specifically, we first selected those areas within the study area with a slope less than 6° and removed the extra patches. Second, we constructed a 5 km buffer zone for the water system map (mainly including the Yellow River, Huangshui River, and its tributaries) and the settlement of the Ming Dynasty. In order to remove the riverbed and floodplain within the river valleys (the riverbed and floodplain were unfavorable for reclamation), the areas of 200 m, 75 m, and 40 m were constructed as buffer zones for the mainstream of the Yellow River, the Huangshui River, and its tributaries, respectively. The obtained riverbed–floodplain layer was removed from the overlapping layer, and the area was controlled at about 446 km².

It should be noted that the Ming Dynasty's record of cropland area excluded the Saiwai cropland area. The medium mountain had become the primary distribution places of Saiwai cropland, and this part was not mentioned in this paper due to the lack of the literature record. The third step was to overlay the above layers to obtain the overlaying layer, in other words, to obtain the distribution of cropland in the Ming Dynasty (the above-stated steps were implemented using ArcGIS 10.5 version 10.5 ESRI, Redlands, CA, USA). The climate of the studied area during the Ming and Qing Dynasties has not changed much compared to the modern climate, and the basic geomorphic of the natural environment also exhibited a consistency. Thus, the distribution of natural vegetation also showed consistency. Except for the reclamation, all the other Ming Dynasty lands conformed to the vertical zonality of vegetation in modern times, so we can use the distribution map of modern vegetation to obtain the distribution map of the vegetation type in the Ming Dynasty.

To reconstruct cropland during the Qing Dynasty, we selected the reclamation rate of the Hehuang valley in the 4th year of the Qing Dynasty (1726 AD). It has been found that the cropland area in the Qing Dynasty, Yongzheng 4th (1726 AD) was 1427 km², while in the Qing Dynasty, Qianlong 11th (1746 AD), it was 2330 km², and in the Qing Dynasty, Xianfeng (1850–1861 AD) it reached 3335 km². This information indicated that the reclamation rate in Qianlong 11th and Xianfeng increased by 3% and 13%, respectively, compared to that in the Qing Dynasty, Yongzheng 4th. Accordingly, we selected the late Ming Dynasty (1640 AD), the Qing Dynasty, Yongzheng 4th (1726 AD), Qianlong (1746 AD), and Xianfeng (1856 AD) as time sections and set the reclamation rate of the Qing Dynasty, Yongzheng 4th as K . Therefore, the reclamation rates of the Qing Dynasty, Qianlong 11th, and Xianfeng were $K + 0.03$ and $K + 0.13$, respectively. Thus, we could obtain the cropland distribution in 1726 AD, 1746 AD, and 1856 AD. The distribution map of the vegetation types in the Qing Dynasty was obtained by overlaying the cropland distribution map during the above three periods of the Qing Dynasty and the vegetation type map from the Ming Dynasty.

3.2.2. Calculation of Water Conservation Capacity

The water balance equation was adopted for the calculation of water conservation capacity, and the formula is as follows:

$$TQ = \sum_{i=1}^j (P_{ij} - R_{ij} - E_i) \times A_i \times 10^3 \quad (1)$$

$$E_i = \sum_{i=1}^{i=12} \frac{A \times R_i}{A + B \times R_i^2 \times \exp\left(-\frac{C \times t_i}{235 + t_i}\right)} \quad (2)$$

In Formula (1), TQ represents the total water conservation quantity (m³), P_{ij} is the annual average precipitation (mm), R_{ij} is the annual average surface runoff (mm), A_i is the area of the ecosystem of class (km²), i is the ecosystem type of type i^{th} in the study area, j is the type number of the ecosystem in the study area, and E_i is the actual annual average evapotranspiration (mm). In Formula (2), A , B , and C are empirical coefficients,

with values of 3100, 1.8, and 34.4, respectively, R_i is the precipitation in the i^{th} month (mm), T_i is the average temperature of the i^{th} month ($^{\circ}\text{C}$), and E_i is calculated by empirical Formula (2) [21].

If the calculation is based on raster data in ArcGIS, the formula is modified as follows:

$$TQ = \sum_{i=1}^i (P_i - R_i - ET_i) \quad (3)$$

In this formula, i is the i^{th} pixel lattice.

Calculation of annual precipitation P_{ij} :

The precipitation in the Ming and Qing Dynasties was different from that in modern times. To correct the data, we reviewed the annual average precipitation series reconstructed in the northeast area of the Qinghai–Tibet Plateau during the historical period [22]. We utilized the annual average precipitation over 30 years of the time section we studied (Table 2) to calculate the difference between the average precipitation of the 30 years and that of 1957–1980.

Table 2. Annual average precipitation of studied time section.

Calendar Year/AD	1629 ± 15	1726 ± 15	1746 ± 15	1856 ± 15
the difference/mm between the average precipitation of 30 years and the average precipitation in 1957–1980	−31.18	−39.7793	−7.30542	−10.6073

The formula is as follows:

$$P_j = P - d_j \quad (4)$$

In this formula, P_j represents the annual average precipitation of time section in year j of the Ming and Qing Dynasties, P is the modern annual average precipitation, and d_j is the difference/mm between the average precipitation of 30 years in year j and the average precipitation in 1957–1980.

Calculation of the annual average surface runoff R_{ij} :

Surface runoff data were obtained by multiplying rainfall by the surface runoff coefficient, and the formula is as follows:

$$R = P \times a \quad (5)$$

In this formula, R represents the surface runoff (mm), P is the multi-year average rainfall (mm), and a is the surface runoff coefficient, as shown in (Table 3):

Table 3. Relationship between vegetation types and surface runoff coefficient in The Hehuang Rivervally.

Number	Vegetation Type	Average Surface Runoff Coefficient/%	Number	Vegetation Type	Average Surface Runoff Coefficient/%
1	Succulent salt dwarf semi-shrub desert	18.27	10	Temperate deciduous shrubs	4.17
2	Alpine sparse vegetation	18.27	11	Temperate deciduous broadleaf forests	1.33

Table 3. Cont.

Number	Vegetation Type	Average Surface Runoff Coefficient/%	Number	Vegetation Type	Average Surface Runoff Coefficient/%
3	Cold-temperate and temperate mountain coniferous forests	0.88	12	Temperate coniferous forests	0.88
4	Grass, carexalpine grassland	4.78	13	No vegetation/glacier	0
5	Kobresia and forb alpine meadow	8.2	14	Subalpine leathery evergreen broadleaf shrubs	4.26
6	Kobresia and forb alpine meadow and subalpine deciduous broadleaf shrubs	8.2	15	Subalpine deciduous broadleaf shrubs	4.17
7	Temperate tufted dwarf grassdwarf semi-shrub desert grassland	4.78	16	Subtropical and tropical mountain coniferous forests	3.02
8	Temperate tufted grass grassland	4.78	17	Subtropical deciduous broadleaf forests	1.33
9	Cultivated crops	18.27	18	Coniferous and broadleaf mixed forests	2.29

4. Results

4.1. Spatial Distribution of Cropland

During the late Ming Dynasty, the croplands were mainly distributed in the Sainei (south of the Great Wall) and the mainstream of the Huangshui and its tributaries, with lower altitude and better hydrothermal conditions, such as Xinachuan, Beichuan, Shatangchuan, Xibaochuan, and Nanchuan valley. In addition, the croplands were also distributed in the Yellow River valley (Figure 3).

The spatial distribution of cropland in the Qing Dynasty exhibited different characteristics from that of the Ming Dynasty. First, in the Qing Dynasty, humans began to expand to the Saiwai, especially after the establishment of Datong Wei in Saiwai in Yongzheng 3rd (1725 AD), resulting in the substantial promotion of reclamation of new cropland. Thus, the reclamation area expanded to the places belonging to Saiwai in the Ming Dynasty, such as the Datong River valley of Menyuan county, the Beichuan River valley in the north and central part of Datong county, the upper reaches of the Huangshui River valley of Huangyuan county, and the tributary river valley of the Yellow River in Xunhua and Tongren. Second, the cropland started into medium mountains in Sainei. It was appropriate to assume that, after the development of the reign in the Qing Dynasty, Shunzhi (1644–1661 AD), and Kangxi (1661–1722 AD), agriculture had become the dominant industry in the area.

Meanwhile, the river valleys of the area had been developed completely (The New Survey of the Xining Prefecture records that during the Qing Dynasty, Qianlong (1736–1796 AD), “All four river valleys around Xining have been entirely reclaimed. Therefore there is no idle land”, indicating that Xining was surrounded by a series of river valleys that had been wholly reclaimed). This resulted in the gradual reclamation to the medium and small undulating mountainous areas at higher elevations. During this process, cropland expanded to the medium and high mountain areas, referred to as the cropland spread into the mountains.

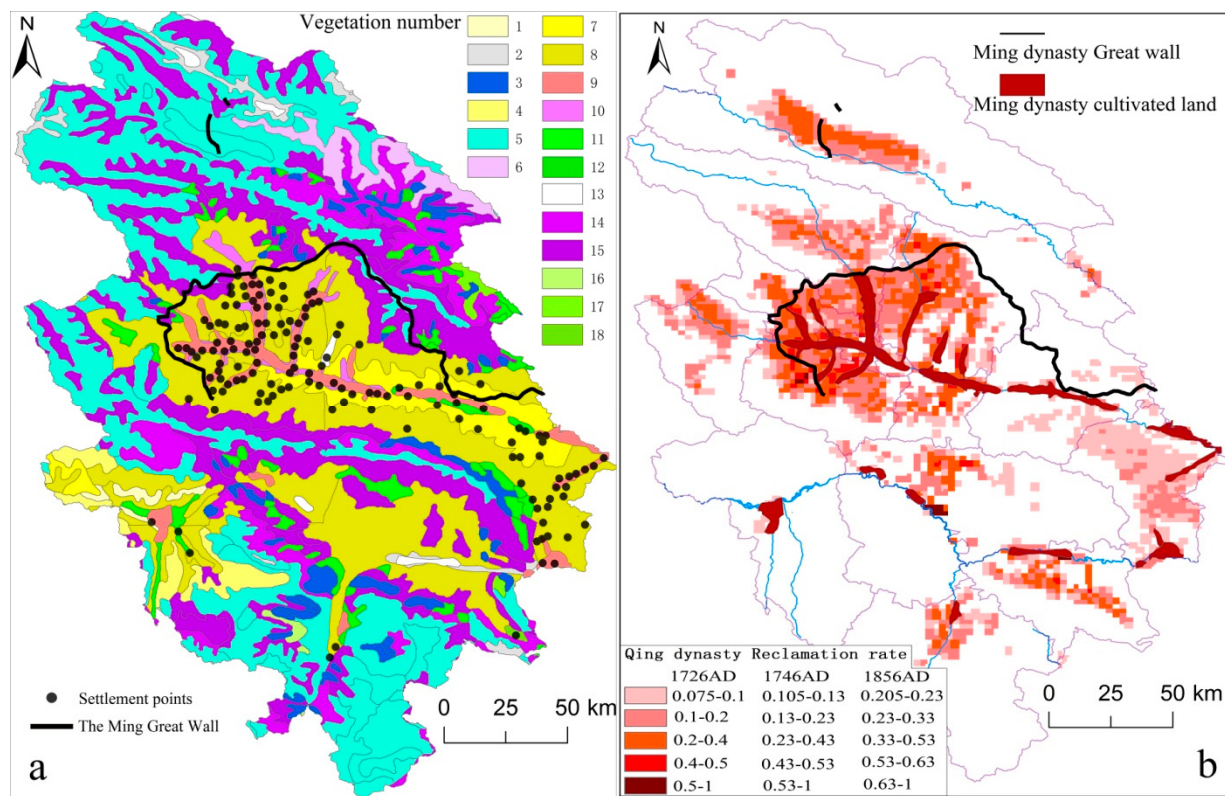


Figure 3. (a) Distribution of cropland–vegetation in 1640AD; (b) Distribution of cropland in the Qing Dynasty in the Hehuang valley. The vegetation type coded in Figure (a) is the same as Table 3 and 9 is the cropland distribution area; In Figure (b), the distribution data of reclamation rate in 1726AD, 1746AD, and 1856AD were obtained through the literature collation [23].

Third, the degree of cropland expansion in Saiwai, where minorities lived, had increased. The appearance of vertical zonality of the natural environment resulted in the noticeable difference between the regions where the Hans and minorities lived. Specifically, most of the Hans were concentrated in the river valley, while the minorities were widely distributed in the medium and high mountain areas. Moreover, it has been revealed that medium and high mountains dominated most regions where minorities were active [24]. The reclamation of cropland in these areas (Sainei) started in the early Yongzheng times, the Qing Dynasty, and the cropland area increased continuously. In the mid-Qing Dynasty, the cropland area in these areas had a dominant position among the total Hehuang cropland area [25]. Around Qianlong 37 AD (1772 AD), this cropland area was nearly half of the total cropland area [26]. The cropland was already saturated at the end of the Qing Dynasty (1796–1850AD).

Overall, most of the new reclamation areas in the Qing Dynasty were located in the medium and high mountain areas, where minorities were active. Moreover, during the mid-Qing Dynasty, the cropland increasingly expanded to the medium and high mountain areas. The literature records show this reclamation behavior appeared within 200 km to the south of Xining city and in the ravines of the medium mountain areas of Lajishan [27].

4.2. The Cropland Development and Destruction of Natural Vegetation during the Qing Dynasty

During the continuous expansion of cropland into the medium and high mountains during the Qing Dynasty, the original natural vegetation was disturbed and destroyed. By the mid-Qing Dynasty, when reclamation was at its peak, 13 of the 16 natural vegetation types (Table 3) were disturbed and destroyed to varying degrees, leaving only the carex alpine grassland undisturbed (there was no or little distribution of temperate deciduous shrubs and subtropical and tropical mountain coniferous forests in the region, so they were neglected). According to the area of cropland reclaimed from natural vegetation during

the Qing Dynasty, 61.2% of the cropland was reclaimed in the temperate tufted-grass growing lands, 14.4% of the cropland was reclaimed from sub-alpine deciduous broad-leaved shrubs, 13.1% was from kobresia and for alpine meadow, 5.7% was from temperate tufted dwarf grass and dwarf semi-shrub desert grassland, 1.5% was from temperate deciduous broad-leaved forests and sparse alpine vegetation, and less than 1% from others (Figure 4). If the temperate tufted grass, temperate tufted dwarf grass, and dwarf semi-shrub desert grassland were all regarded as the temperate steppe, 66.9% of the cropland was reclaimed from the temperate steppe in the middle. Small undulating medium mountains, and 10% of the cropland was from the alpine shrubs and alpine meadows in the large undulating high mountains. Other vegetation types were much less affected.

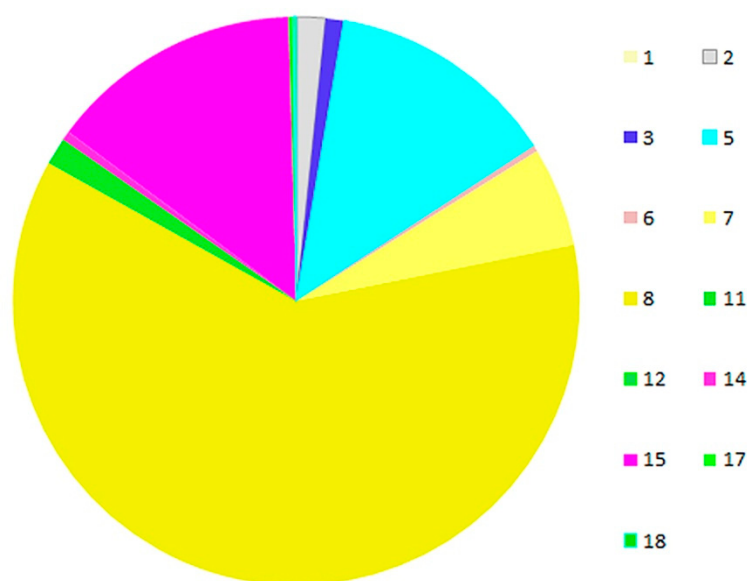


Figure 4. The proportion of new cultivated land in different vegetation types in Qing Dynasty. The vegetation numbers are same as (Table 3).

According to the natural vegetation types reclaimed as cropland, by 1856AD, approximately 18.89% of the coniferous and broad-leaved mixed forests, 16.8% of temperate tufted grass growing grassland, 10.29% of temperate tufted dwarf grass-dwarf semi-shrub desert grassland, 6.63% of sparse alpine vegetation, 5.93% of subtropical deciduous broad-leaved forests, 5.22% of temperate deciduous broad-leaved forests, 4.9% of subalpine deciduous broad-leaved shrubs, and 3.31% of kobresia and for alpine meadow were reclaimed as cropland. Generally, 32.58% of the forest, 27.09% of the temperate steppe, 5.47% of the shrubs, 6.63% of the sparse alpine vegetation, and 3.31% of the alpine meadow were reclaimed as cropland during the middle of Qing Dynasty. In other words, the destruction appeared to impact 1/3 of the forest and grassland in the entire area. From 1726–1856AD, the proportion of cropland in the natural vegetation area exhibited an increasingly growing trend. For example, the proportion of cropland in temperate tufted grass growing grassland was 9.82% in 1726AD, it increased to 9.82% in 1746AD, and it reached 16.8% in 1856AD (Table 4). The above-stated point has been revealed in the literature, according to the local chronicles, in 1730AD, the forest in the Longwu River valley of Tongren, which was part of the Xunhua County at that time, was cut down and reclaimed as cropland in order to construct Xunhuacity [28].

Table 4. Proportion of natural vegetation types reclaimed into cropland at three research time sections during the Qing Dynasty.

Number	Vegetation Type	Area of Regional Vegetation Type/km ²	Proportion of Cropland in the Area of the Vegetation Type/%		
			1726AD	1746AD	1856AD
1	Succulent salt dwarf semi-shrub desert	195.37	0.32	0.44	0.86
2	Alpine sparse vegetation	667.14	4.04	3.36	6.63
3	Cold-temperate and temperate mountain coniferous forests	1458.91	1.21	1.51	2.5
4	\	\	\	\	\
5	Kobresia, forb alpine meadow	11988.95	1.84	2.18	3.31
6	Kobresia and forb alpine meadow + subalpine deciduous broadleaf shrubs	850.17	0.67	0.85	1.44
7	Temperate tufted dwarf grass dwarf semi-shrub desert grassland	1877.26	5.07	6.27	10.29
8	Temperate tufted grass grassland	10463.02	9.82	11.07	16.8
9	\	\	\	\	\
10	\	\	\	\	\
11	Temperate deciduous broadleaf forests	1016.34	2.55	3.16	5.22
12	Temperate coniferous forests	27.08	0.02	0.02	0.04
13	\	\	\	\	\
14	Subalpine leathery evergreen broadleaf shrubs	2711.01	0.31	0.37	0.57
15	Subalpine deciduous broadleaf shrubs	9291.04	2.6	3.13	4.9
16	\	\	\	\	\
17	Subtropical deciduous broadleaf forests	160.07	2.86	3.57	5.93
18	Coniferous and broadleaf mixed forests	28.99	9.68	11.8	18.89

Note:(vegetation number is same as Table 3).

4.3. Changes in Water Conservation Capacity during the Ming and Qing Dynasties

The destruction of natural vegetation in the medium and high mountain areas and the conversion of many forests and grasslands into cropland caused significant changes in underlying surface properties and conservation capacity [29]. The studied area located in the arid and semi-arid area with intense evapotranspiration and loss of surface runoff resulted in a diminished water conservation capacity. (Table 5) shows the changes in water conservation capacity caused by the cropland spreading into the mountains of the Hehuang valley during the Ming and Qing Dynasties. In 1640AD, the water conservation capacity was about $-7.47 \times 10^7 \text{ m}^3$, but by 1726AD, the acceleration of cropland spreading into the mountains significantly decreased the water conservation capacity by 4.5 times, to $-33.83 \times 10^7 \text{ m}^3$.

By 1746AD, the water conservation capacity decreased to $-40.36 \times 10^7 \text{ m}^3$. By 1856AD, a peak period for cropland spreading into mountains, the water conservation capacity decreased to $-60.23 \times 10^7 \text{ m}^3$, about eighttimes lower than that in the late Ming Dynasty and nearly onetime lower than that in 1726AD.

Table 5. The changes in the distribution of water conservation capacity in the Hehuang valley during the Ming and Qing Dynasties.

Calendar Year/AD	Ming Dynasty, 1640AD	Yongzheng4th, 1726AD	Qianlong11th, 1746AD	Xianfeng6th, 1856AD
Water conservation capacity/ 10^7 m^3	−7.47	−33.83	−40.36	−60.23
Population	109,490	\	245,735	874,418
Cropland/mu	669,800	2,139,430	3,350,000	5,000,000
Per mu yield	92	92	92	92
Per capita grain	562.8	\	1254.2	526.06

According to the perspective of spatial distribution, from the late Ming Dynasty to the mid-Qing Dynasty, the area with decreasing water conservation capacity was mainly concentrated in the mountain areas that had been cultivated, such as the small and middle undulating medium mountains and some large undulating high mountains. Specifically, the areas with reduced water conservation capacity were mainly distributed in the Huangshui River basin (Huangyuan in the upper reaches of the Huangshui River, and Xinachuan, Yunguchuan, Beichuan, Shatangchuan, and Nanchuan in the middle reaches of the Huangshui River), the Menyuan basin in Datong River basin, the Xunhua basin in the Yellow River basin and its tributaries of Longwu River; in particular, the north of the Huangshui River and the Menyuan basin exhibited a significantly decreasing water conservation capacity. Meanwhile, in other areas with less human interference, the water conservation capacity increased slightly due to an increase in precipitation in the mid-Qing Dynasty compared to the late Ming Dynasty. According to the perspective of the whole area, from the late Ming Dynasty to the mid-Qing Dynasty, the intensity and scale of the continuous expansion of human reclamation resulted in a rapid decline in water conservation capacity (Figure 5).

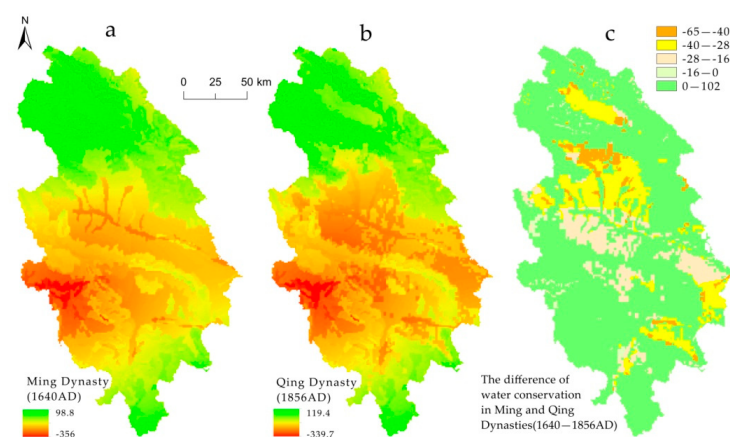


Figure 5. The water conservation in Ming and Qing Dynasty of the Hehuang valley. (a) Ming Dynasty (1640AD); (b) Qing Dynasty (1856AD); (c) The difference of water conservation in Ming and Qing Dynasties (1640–1856AD).

5. Discussion

5.1. Decline of Regional Water Conservation Capacity and Water Damage

During the Qing Dynasty, the cropland spreading into mountains destroyed forest and grassland, reduced water conservation capacity, and declined soil water storage capacity in the medium and part of high mountain areas. These natural conditions could cause both floods and drought [30]. Flood occurs due to the loss of soil and water on slopes during a rainstorm, which forms water logging and debris flow, resulting in water erosion and sand pressure, causing damage to the paddy fields in the river valley. Drought can be divided into atmospheric drought and soil drought; the former refers to the phenomenon of withering caused by low precipitation, high temperature, and low relative humidity, and under these conditions, the crop evapotranspiration is far greater than the water absorption of the root system, leading to the destruction of water balance in the plant and the occurrence of withering; the latter refers to that soil moisture cannot meet the need of crop growth [31]. Therefore, it is evident that a reduction of soil water conservation capacity would lead to soil drought, leading to drought [32].

Since the Ming Dynasty, the studied area's statistical results of drought, flood, water erosion, and sand pressure [33] (Figure 6) showed that drought was the most common and had the most significant disaster loss. The drought frequency in the Ming Dynasty was 2–4 times/10a, and the flood frequency increased significantly from 1775 to 1850 AD, reaching 2–7 times/10a. The flood frequency remained stable until 1725 AD, while it increased from 1725 to 1860 AD and reached 2–7 times/10a. The earliest recorded disaster of water erosion and sand pressure was in 1736 AD, which happened in Guide; more than 2000 mu of cropland were damaged. Since 1775 AD, water erosion and sand pressure frequency increased, reaching the maximum during 1800–1850 AD, and then declined gradually. For example, in 1847 AD, over 18,199 mu of cropland were destroyed. The paddy fields in the river valleys with relatively good land quality and high yield were an atypical example of cropland expansion.

In conclusion, the frequency and intensity of the three types of natural disasters, drought, flood, and sand pressure, were higher during 1775–1850 AD. Coincidentally, this was the peak period for cropland to spread into the mountains. This finding revealed that improper human activities, such as expanding cropland into mountains, led to significant negative impacts on the natural environment and resulted in the destruction of natural vegetation, which was closely related to disasters such as drought, flood, water erosion, and sand pressure [29].

According to the perspective of precipitation change in the studied area, there were many extreme events with little precipitation in the 19th century. Extreme drought with precipitation less than 100 mm in a year occurred in 1824, 1831, 1861, and 1895 AD, with the first two years having precipitation of 201 and 127 mm less than the average precipitation. These four extreme events were typical examples of atmospheric droughts. However, for the first two droughts, only a short and straightforward description was found in the historical documents “drought in Xining, Ledu and Datong”, corresponding to the previous two drought events. No disaster losses or occurrence of severe social unrest were mentioned.

In contrast, for the last two droughts, the historical data recorded dire consequences: “seven counties in Xining Prefecture were in a state of great hunger, people eat each other, the east and west rivers of Guide are dried up, and it is a year of famine” (1865 AD), and “It is dry in Pingan area, and people are suffering from hunger. Xunhua had undergone a drought, harvested only 7/10 of the cropland.” (1893 AD). Despite these records, according to the perspective of precipitation change, the degree of atmospheric drought in 1861 and 1895 AD was not more significant than that of the first two droughts. However, the disaster loss was more significant, which might be associated with the growing population in the mid-Qing Dynasty, leading to increased exposure to disaster-affected areas and more severe disaster losses. This also indicated that the destruction of water conservation capacity in medium and some high mountains were closely related to the soil drought.

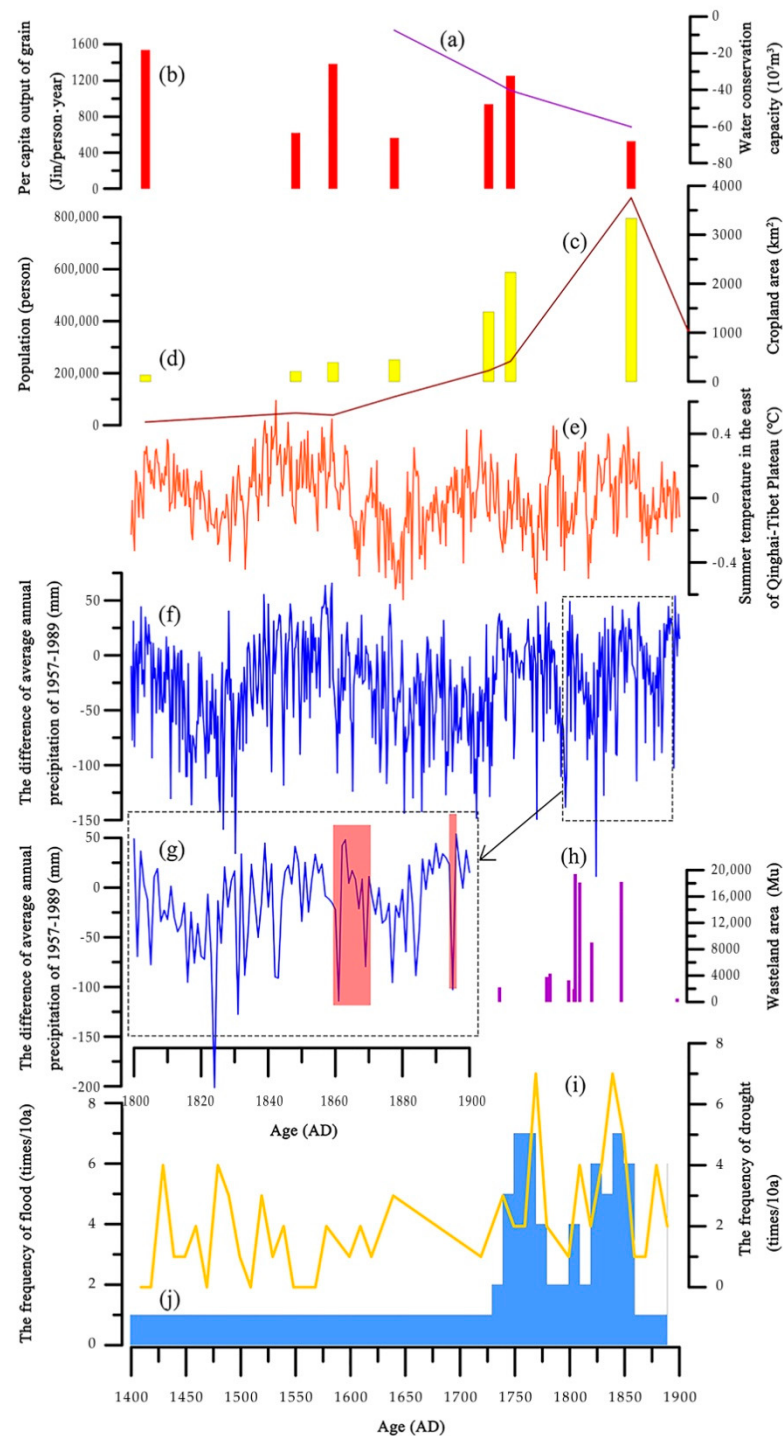


Figure 6. Comparison of water conservation capacity with climate, natural disasters, and social indicators in the Hehuang valley during the Ming and Qing Dynasties. Note: (a) Water conservation capacity (this study), (b) Per capita output of grain (this study), (c) Population [12,14,15], (d) Cropland area [12,14,15], (e) Summer temperature in the east of Qinghai-Tibet Plateau [34], (f) 1400–1900 AD precipitation variation [22], (g) 1800–1900 AD precipitation variation [22], (h) Wasteland area [26], (i) The frequency of drought [33], and (j) The frequency of flood [32].

5.2. Decline of Regional Water Conservation Capacity and Social Upheaval

River valleys have abundant water resources, fertile soil, and high grain yield. In the mid-Qing Dynasty, the increase in cropland areas mainly occurred in medium and some high mountain areas, where soil nutrients were insufficient, fertility was weak, and soil

and water were easy to lose; therefore, the yield was meager (According to the Records of Danger in the late Qing Dynasty, “the flat paddy field covers an area of more than 50 square meters, and the dry hillside land covers an area of more than 300 square meters. In addition, half of the area is in unfavorable conditions for reclamation as gravel, saline soil, and barren land. The agricultural production is insufficient to support people to for leading an impoverished life”). Therefore, a large cropland area was reclaimed in the mountains during the Qing Dynasty, but its output was limited and could support their living only when the population was moderate. However, with the saturation of cropland during the mid-Qing Dynasty, not only the cropland reached a maximum of 5 million mu, but also the population reached a maximum of 874,000 since the Ming and Qing Dynasties.

Further increase in population growth during the mid-Qing Dynasty was bound to create an imbalance between the population and the carrying capacity of cropland, thus triggering social upheavals. During the Ming and Qing Dynasties, highland barley and wheat were the main grain crops in this area. According to the statistical survey in 1934AD, the per mu yields of these two crops were 94.7 Jin and 89.5 Jin, respectively [35]. From the late Ming Dynasty to the mid-Qing Dynasty, the per capita grain value was the highest during the Qianlong times in the Qing Dynasty (it was also recorded in historical documents that granaries were built in the Hehuang valley at that time, and grain was in surplus); in contrast, the per capita grain value reached the lowest point in 1856AD since the Ming and Qing Dynasty. The contradiction between human needs and cropland reached its peak during the mid-Qing Dynasty.

Moreover, some natural factors, such as degradation of the ecological environment in the medium and some high mountain areas, a decline of water conservation capacity, and extreme climate conditions, and some social factors, such as population growth, low productivity, improper policies (such as heavy taxes and levies), and religious disputes, resulted in imminent social upheavals. In other words, the degradation of the regional ecological environment and the decline of water conservation capacity were critical driving forces in that destruction. It is, therefore, appropriate to assume that the drought in 1861 and 1895AD was the key to igniting the fire of social upheaval.

The events and times recorded in the historical document correspond with our research. In the Gansu and Qinghai areas of the upper reaches of the Yellow River, there was a successive drought, of which the most severe year was 1865AD. From 1860 to 1874AD, a large-scale war occurred in the research area, which led to the displacement of people, profound population loss, and extreme economic depression. In Tongzhi 13th (1874AD), an officer recorded Ledu district as “full of desolation, lush fields with several or dozens of sporadic castles and refugees, people are suffering from poverty, and being extremely miserable” (Yushi’s draft in Qinghai). Additionally, in 1891, there was a record of prolonged drought, poor harvest, and soaring grain prices, but the taxes and levies were still heavy. In Xunhua area, for example, the price of grain rose 15 times, and the harvest was only 70% of a general year. The idea that “there was no wheat flour in the cabinet, no grass in the livestock trough, and the time had come to rebel” began to spread in society. Hence there was an outbreak of violent social upheaval, historically known as the “Hehuang incident”, which caused a sharp decline in the population; the population decreased from 510,000 in the Xianfeng period to 364,418 in Guangxu 34 (1908AD), with a reduction of 58.69%. The two upheavals also caused significant damage to the social economy (Table 5).

6. Conclusions

The main conclusions are as follows:

1. The cropland in the Ming Dynasty was mainly distributed in the river valley of Sainei; during the early and mid-Qing Dynasty, the cropland reclamation broke the boundary of the Great Wall. It expanded to the valleys of the Datong River in Menyuan, the Beichuan River in Datong, the upper reaches of the Huangshui River, and the Yellow River’s tributary in Xunhua and Tongren. In Sainei, the cropland expanded to the middle and small undulating medium mountain areas and some large undulating

- high mountain areas, and the reclamation in minority areas aggravated this trend. In the mid-Qing Dynasty, cropland expansion reached its peak, reaching about 7.5 times that in the late Ming Dynasty, and after that, the cropland area began to shrink.
2. The expansion of cropland into mountains caused serious damage to the natural vegetation. As a result, 32.58% of the forest, 27.09% of the temperate grassland, 5.47% of the shrubs, 6.63% of the sparse alpine vegetation, and 3.31% of the alpine meadow had been deeply destroyed by the expansion of cropland to mountains, and ultimately turned the natural vegetation to cropland.
 3. Due to the disturbance and destruction of natural vegetation, the water conservation capacity of the medium and some high mountain areas decreased rapidly. At the end of the Ming Dynasty in 1640AD, the water conservation capacity was about $-7.47 \times 10^7 \text{ m}^3$. By 1726AD, the water conservation capacity decreased over 4.5 times. By 1856AD, the cropland spread into mountains reached its peak, and the water conservation capacity decreased by about eight times compared to the late Ming dynasty.
 4. Drought events, floods, and soil erosion mainly occurred from 1775 to 1850AD, consistent with the croplands' rapid expansion to the mountainous areas during the mid-Qing Dynasty. This indicates that the expansion of cropland had led to decreased water conservation capacity, which eventually resulted in various natural disasters in the area.
 5. Most of the newly cultivated lands were concentrated in the medium and part of high mountain areas; these areas had a low yield. By the mid-Qing Dynasty, the population was still growing. Therefore, the grain yield could not meet the demands of the expanding population. In addition, due to both natural and social factors, two social upheavals occurred in the late Qing Dynasty, which significantly affected the development of the regional social economy.

Author Contributions: Ideas, formulation or evolution of overarching research goals and aims, G.H.; Conceptualization, Z.H., Z.L., G.H.; methodology, software, data curation, and validation, Z.H., Z.L.; writing—review and editing, Z.H.; Preparation, creation and/or presentation of the published work, visualization, Z.H.; All authors have read and agreed to the published version of the manuscript.

Funding: 1. Natural Science Foundation of China (Grant Nos. 42171165). 2. Natural Science Foundation of China (Grant Nos. 42261030).

Institutional Review Board Statement: This study did not involve humans or animals.

Informed Consent Statement: This study did not involve humans.

Data Availability Statement: All data presented in this study are available in article.

Acknowledgments: We would like to thank Zhuoma Wende, Xiaoqing Li, Baozheng Qi, and Jiang Rong from Qinghai Normal University for their valuable comments on the article. All individuals included in this section have consented to the acknowledgement.

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

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