sustainability

Review

Desertification Control Practices in China

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Abstract: Desertification is a form of land degradation principally in semi-arid and arid areas influenced by climatic and human factors. As a country plagued by extensive sandy desertification and frequent sandstorms and dust storms, China has been trying to find ways to achieve the sustainable management of desertified lands. This paper reviewed the impact of climate change and anthropogenic activities on desertified areas, and the effort, outcome, and lessons learned from desertification control in China. Although drying and warming trends and growing population pressures exist in those areas, the expanding trend of desertified land achieved an overall reversal. In the past six decades, many efforts, including government policies, forestry, and desertification control programs, combined with eco-industrialization development, have been integrated to control the desertification in northern China. Positive human intervention including afforestation, and the rehabilitation of mobile sandy land, and water conservation have facilitated the return of arid and semi-arid ecosystems to a more balanced state. China's practices in desertification control could provide valuable knowledge for sustainable desertified land management on a global scale.

Keywords: desertification; climate change; forestry and desertification control program; ecological industrial engineering; China

1. Introduction

Desertification results from factors related to long-term natural and social-economic interactions [1]. The Earth's surface consists of 41% dryland that houses more than one-third of the global population [2,3]. Approximately 25% of dryland is under threat from desertification [4]. There have been economic losses of approximately US$42.3 billion due to worldwide desertification [5]. The cost of worldwide desertified land consolidation was estimated at approximately US$141 billion [6]. In European Union countries, the economic and social costs of land degradation can amount to US$57 billion per year [7]. In China, the desertification-induced economic loss was estimated at US$6.8 billion annually [8]. Raised costs of protection efforts, depreciation of land values, food insecurity, health care, fertility and crop losses, and damage to human lives are some of the noted effects of desertified lands [9,10]. Desertification and drought cause 12 million hectares of productive land to become barren each year, which leads to grain production losses of 20 million tons [11].

Climate change together with human activities influences desertification. Worldwide land degradation will likely increase in the future due to climate change and the growth of populations [12,13].

Desertification is affected positively or negatively by variations in temperature, rainfall, and wind regimes. The increase of temperature and wind speed and the decrease of rainfall could cause a decline in vegetation [14,15]. Human disturbances intensify the degree of regional sandy desertification [16,17]. The increasing population, along with deep desires of alleviating poverty and creating prosperity, results in intensified human activities that negatively impact the environment. These activities include overgrazing, overcultivation, excessive collection of firewood, and unsustainable land and water use. Although determining the exact level of the effects both climatic and human influences have on the desertification process is still a major challenge for scientists, there is no doubt that proactive responses to desertification could prevent further desertification and improve the environment in desertified areas [18–21].

Desertification has brought the expansion of desert-like characteristics in non-desert areas throughout human history and is a major obstacle for sustainable development. Desertification occurs widely when human activities disturb the balance of arid, semi-arid, and semi-humid ecologies, with climatic fluctuation as a key dynamic factor [22,23]. Without efficient measures of desertification control, the externalization of degradation costs will persist, and desertification will result in acute sustainability issues for the coming generations [7]. Effective desertification control has the aim of improving the well-being of local residents and could reverse desertification and promote sustainable development.

Over the last six decades, governments and researchers in Asia, Africa, Europe, America, Australia, etc. have made great efforts to manage desertification [24–27]. However, governing desertification remains a difficult task to solve [28–30]. This paper presents an analysis of the influences of climate change and human activities on desertification, as well as Chinese political and economic practices. Providing effective ways to achieve win-win cooperation among stakeholders, including the central government, local governments, farmers, and herdsmen to mitigate desertification is one main objective. These findings could be helpful for desertification control worldwide.

The article is structured as follows: 1. Introduction; 2. Materials and Methods; 3. Drying and warming trends in desertified areas; 4. Anthropogenic impact on desertification; 5. A series of human proactive responses playing the main role in desertification control; 6. Discussions; 7. Conclusions.

2. Materials and Methods

2.1. Data Sources

The source of 1 km raster data of land use type in 2015 was the Institute of Geographic Sciences and Natural Resources Research and the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (http://www.resdc.cn). This dataset used Landsat TM/ETM+ and Landsat 8 remote sensing images to obtain the land use data in China. The regional distribution of land use types was mapped using ArcGIS. The land use was classified into 12 categories: farmland, woodland, grassland, water bodies, residential land, sandy land, Gobi, saline land, wetland, bare land, bare rock boulder, and others.

Daily wind speed and direction at 119 stations in northern China from 1951 to 2013 were collected from the Chinese Meteorological Administration to analyze the annual potential sand transport flux. Annual mean wind speed (V_{am}) is the average of daily wind speed. Population growth rate and livestock growth data were provided by Bureau of Statistics, China. The data of the total area of desertified land and sandy desertified land was from the Office to Combat Desertification of China.

2.2. Sand Transportation Flux

To investigate the intensity of aeolian sand process, sand transport rate (q_s) and corresponding wind speed (u) on shifting, semifixed and fixed sand surfaces were observed in Mu Us sandy land and

Qubqi sand desert, two typical areas of sandification in northern China [31]. The relationship between q_s and u on shifting sand surface could be expressed as:

$$q_s = 0.4074 \times 1.6453^{u} \quad (1)$$

By analyzing the meteorological 10 min resolution wind data, three specific parameters (wind speed, duration, and direction) were identified decisive for sand transport, and thus used to quantify annual potential shifting sand transport flux (Q_s):

$$Q_s = \sum q_s \times T_i \quad (2)$$

where T_i is the duration of annual sand transporting winds at different speed levels and in different wind directions. Annual Q_s in all 16 wind directions is obtained by vector operation [32].

2.3. Methodological Framework

Climate change and human activities combine together to influence desertification. Figure 1 shows the flowchart of the methodology adopted in this study for determining the natural and anthropogenic impact factors on desertification control in China.

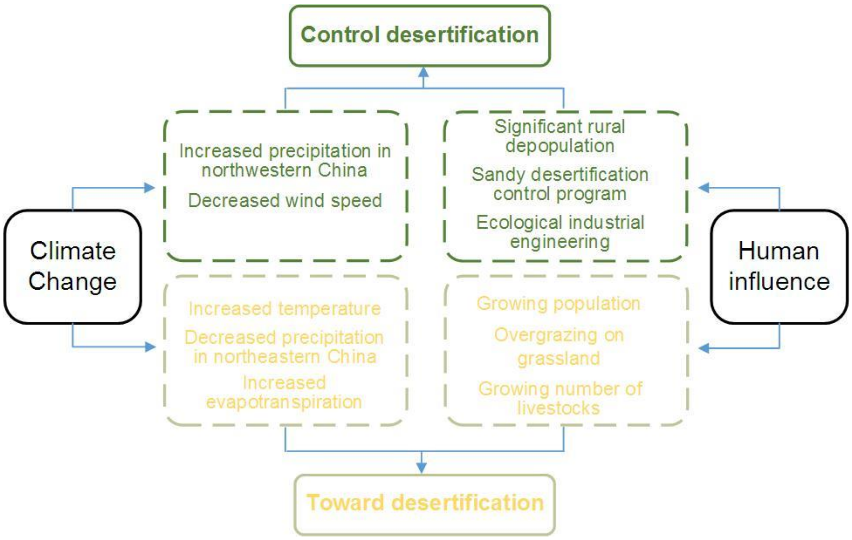

Figure 1. Flowchart of the methodology.

3. Drying and Warming Trends in Desertified Areas

Desertified areas in northern China span dry sub-humid, semi-arid, arid, and hyper-arid climatic zones from northeast to northwest. The desertified area includes five land use types which are sandy land, Gobi, saline land, bare land, and bare rock boulder. In northern China, the area of the five land use types accounts for 29.3% of the total land area (Figure 2).

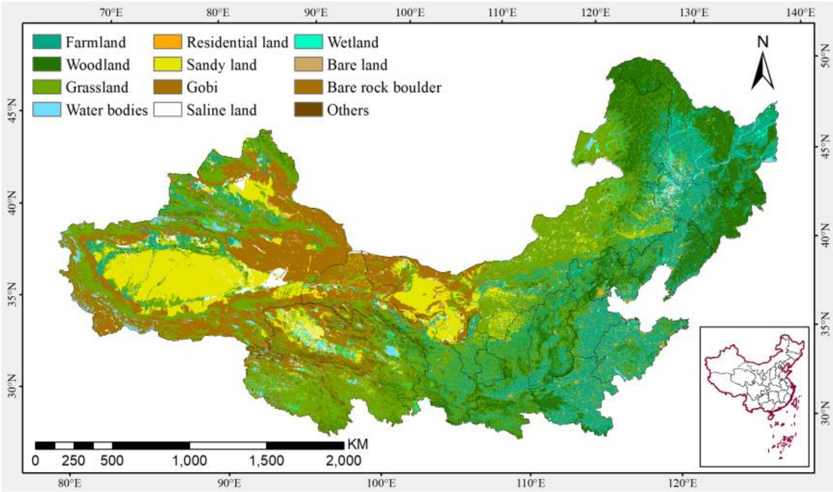

Figure 2. Distribution of the desertified land in China.

3.1. Differences in the Rainfall between Northeastern and Northwestern China

Dominated by the East Asian monsoons, precipitation in China exhibits high variability and significant regional differentiation [33]. Based on the data from 533 rain gauge stations, a long-term drying trend has been observed in northern China since 1961 [34]. However, there is a significant regional contrast among precipitation trends [35]. Northwestern China's arid regions have experienced more rainfall than northeastern China, at a decadal rate of 6.8 mm, especially during winter and spring. By contrast, the semi-arid and sub-humid regions of northern China and northeastern China are receiving increasingly less precipitation, at a rate of decrease of 10.0 mm every 10 years, mainly in the summer.

Increases in rainfall in northwestern China have resulted in higher lake levels along with larger amounts of vegetative cover in the desert margins [36] and could thus promote reduced wind-driven soil erosion and desertification. However, drying in northern and northeastern China can cause significant drought increases. Spanning several recent decades, northern China has experienced several serious droughts [37,38]. Frequent outbursts of sand and dust storms in 2000 resulted from a late 1990s drought of severe proportions [39]. Drought-induced wind erosion, blown sand drifts, sandy desertification, and sand and dust storms all integrated together, constituting the most prominent natural disaster chain in northern China.

3.2. Northern China's Trend of Fast Warming

Strong increases of warming have occurred throughout China during the past five decades, and China's northern areas exhibited the fastest warming rate [40]. According to measurements from 537 meteorological stations, a per decade average temperature increase rate of 0.41 °C for northern and northeastern China and a 0.38 °C increase in northwestern China were documented [34]. An approximate increase of 2 °C in annual temperatures has been observed since 1961, which would have increased the per year potential evapotranspiration (PET) by approximately 150 mm, surpassing the increases in precipitation in the northwestern arid regions [41]. Thus, warming may have mitigated the higher precipitation in the northwest and exacerbated the desiccation of soil in northern China.

3.3. Northern China's Decreased Surface Wind

The direct driving factor in soil erosion and desertification is near surface winds. High wind activities are strongly associated with high risks of desertification for both semi-arid and arid areas along with some semi-humid areas [42]. Biological processes, such as variations in vegetation cover, influence desertification; however, for sandy desertification, physical processes, such as wind activity, are the most important factors at play [43]. Observation data based on reports from 119 meteorological stations showed that the annual mean wind speed (MWS) in China's north has been 2.6 m s^{-1} over the last 60 years (Figure 3). The MWS was 2.8 m s^{-1} in the 1950s and 2.5 m s^{-1} for the 1980s and decreased to 2.4 m s^{-1} for the 2000s. The calculated annual mean potential sand transport flux was 18.4 t m^{-1} a^{-1} over the last 60 years, with a maximum of 47.6 t m^{-1} a^{-1} in 1969 and a minimum of 7.4 t m^{-1} a^{-1} after 2000 (Figure 4). Strong wind days along with maximum winds across large areas of China indicate declining trends [44]. Success with desertification rehabilitation may be partly attributed to the lowered wind speed and transportation of sand [45].

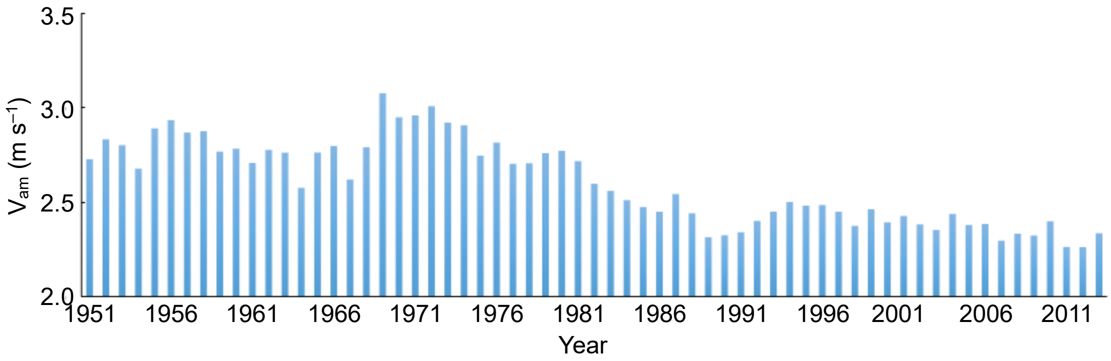

Figure 3. Annual mean wind speed (V_{am}) in northern China from 1951 to 2013.

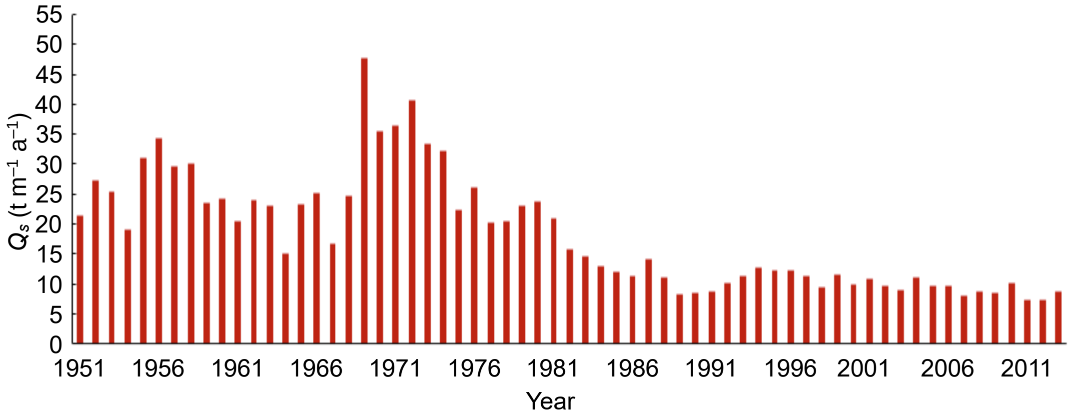

Figure 4. The annual potential sand transport flux (Qs) in northern China since 1951.

The key questions are whether the recently observed drier northeastern China and wetter northwestern China have, as a whole, intensified or mitigated desertification and how much of the fast warming trend and decrease in surface wind in northern China was induced by changes in the land usage and the increased speed of urbanization opposed to worldwide climatic changes [46]. To improve the understanding of climate impacts on desertification, anthropogenic influences of urbanization as well as changes in land-use on climate, especially in arid, semi-arid, and dry sub-humid areas, require an increased focus [47].

4. Anthropogenic Impact on Desertification

4.1. Growing Population Pressure on Land

China's mean population density of 141 people per square kilometer, which is approximately three times higher than the worldwide average, makes it the most populous country on earth. Divided by the Hu Huanyong Line (or Heihe-Tengchong Line) from northeast to southwest, the population distribution of China has sharp regional differences [48]. In the southeastern areas, 94% of the country's population lives within 43% of the country's land area [48]. The density of population of China's northwest, with 39 people per square kilometer in the semi-arid areas and 8 people per square kilometer in the arid areas, is comparably low [49]. Nevertheless, the population pressure on China's desertified areas has exceeded the population supporting capacity threshold of 20 people per square kilometer in semi-arid land and 7 people per square kilometer in arid land, as proposed by the UN in 1977 [50].

The growth of the population that depends on the resources of dryland is the most dramatic process of social change that is associated with desertification. With the implementation of the one-child policy in the 1970s, China decreased the rate of its population growth from over 20‰ to approximately 5‰ at present (Figure 5a). However, due to a relatively looser fertility policy for ethnic minorities and the western development policy, the northwestern regions had a faster annual population growth rate (10.9‰) than the overall annual growth rate of China (9.6‰) from 1980 to 2015 (Figure 5b). Despite China's various efforts to slow the population growth by reducing fertility, the population continually increased by 39.3% from 1980 to 2015, with arid and semi-arid areas having a population of over 125 million in 2015 (Table S1).

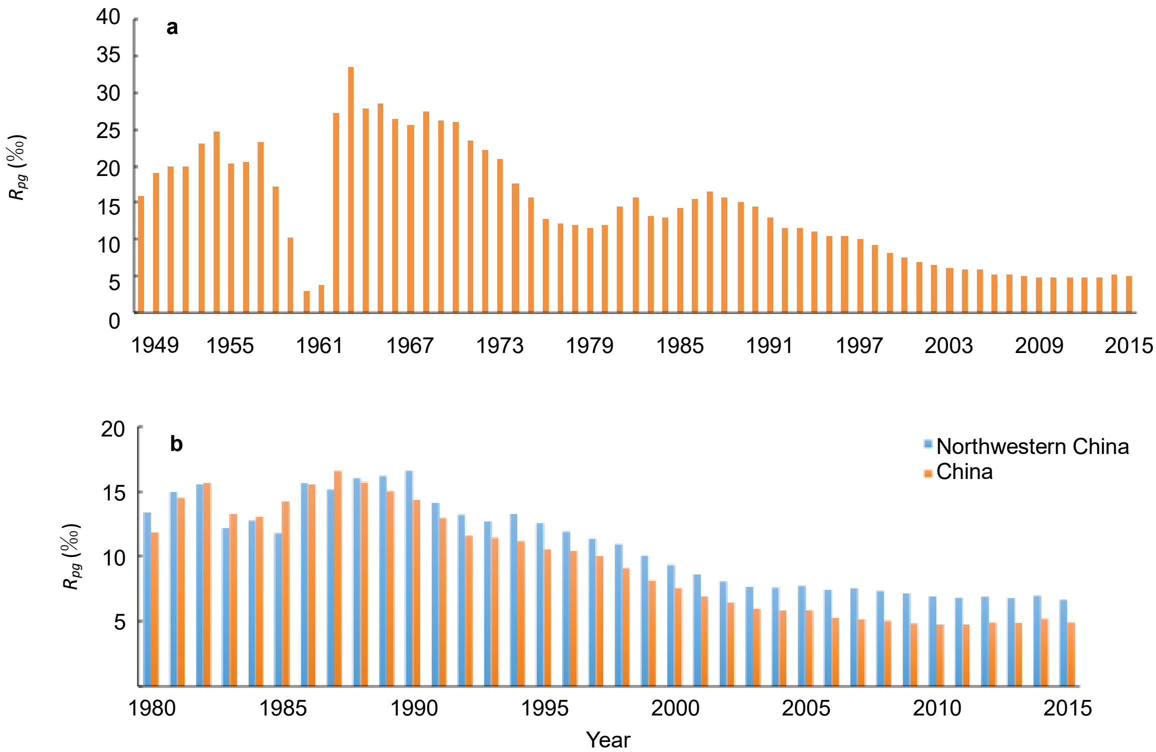

Figure 5. The population growth rate (R_{pg}) in China: (**a**) R_{pg} in China from 1949 to 2015; (**b**) R_{pg} in northwestern China and China from 1980 to 2015.

4.2. *Significant Rural Depopulation*

In the past three decades, China's fast urban development brought significant rural depopulation. The population increased for urban proportions from 21.1% in 1982 to 56.1% in 2015 [51]. Over this same period, the rural population had an absolute reduction, and the rural proportion decreased from 77.6% in 1982 to 48.3% in 2015 for the northwestern arid and semi-arid regions (Table 1 in SI). Although the relationship between population dynamics and desertification is complex and nonlinear, demographic variables remain imperfect indicators of the risk to biodiversity, along with land erosion and desertification. Under high population increases and human activities, substantial human-induced environmental changes have occurred and are sure to persist in the future. However, rural depopulation may directly reduce disturbances on dryland pressure and may be a contributor to desertification rehabilitation.

Table 1. Changes in the total area of desertified land and sandy desertified land in China since 1994.

Years	Total Area of Desertified Land (million km^2)	Total Area of Sandy Desertified Land (million km^2)	The Average Annual Increase/Decrease Rate of Sandy Desertified Land (km^2/year)
2014	2.612	1.7212	− 1980
2009	2.624	1.7311	− 1717
2004	2.636	1.7396	− 1283
1999	2.674	1.7431	+ 3436
1994	2.622	1.6889	+ 2460

4.3. Overgrazing on Existing Grassland

Since 1949, the number of livestock in northwestern China has exhibited an increasing trend (Figure 6). In 2008, the grassland area was 236.8 million ha, and the total forage reserve of 264 pastoral counties was 136.16 million tons [51]. The actual livestock burden was 276.8 million sheep units, exceeding the rational carrying capacity (207.2 million sheep unit) by 33.6% [51]. Grassland degradation is normally related to stocking pressure. The highest stocking density in the sub-humid area with 400–500 mm annual rainfall causes soil erosion and desertification from blowouts.

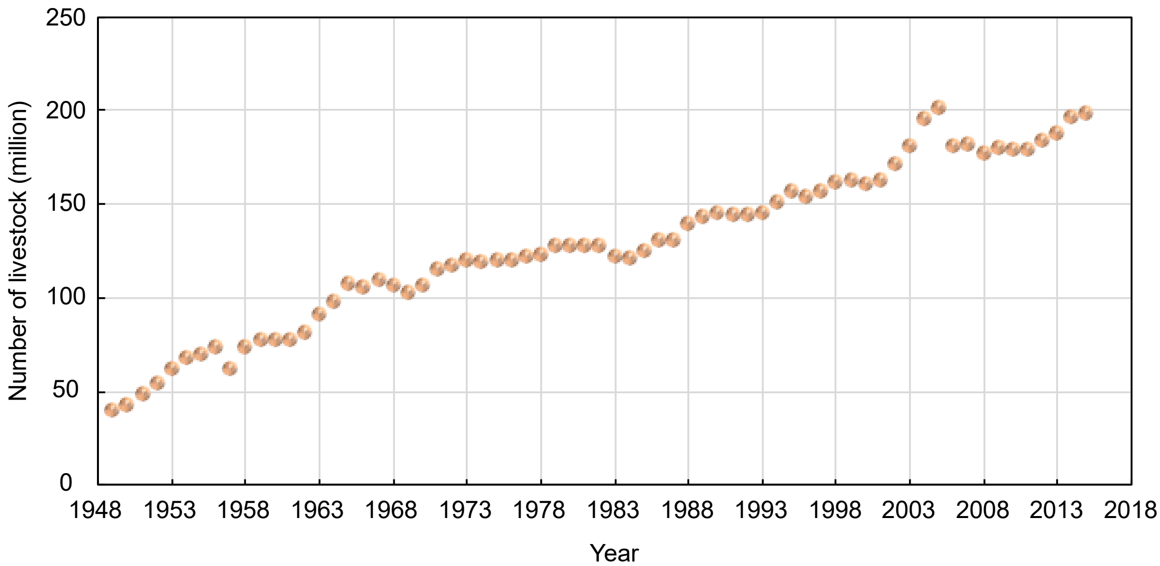

Figure 6. Livestock growth in northwestern China from 1949 to 2015.

5. A Series of Proactive Human Responses Playing the Main Role in Desertification Control

Six decades of practice of desertification control in China demonstrates that, even under the influence of global warming, a negative growth of desertified land has been achieved (Table 1). What are the key factors of China's success? What does China's success in combating national desertification mean for the global goal of stopping desertification growth worldwide?

5.1. Government-Supported Vegetation Construction in Desertified Areas

China is a country that has a large proportion of the world's population but a meager proportion of its land while frequent flood, drought, and serious blown sand problems continue to be faced. Therefore, disaster reduction and the control of desertification are of high importance to the government. In 1958, in Hohhot, the first sand control planning meeting jointly held by the Central Committee and the State Council saw the drafting of the desert control plan, thus launching a massive campaign on desert transformation and governance. From 1959, a comprehensive investigation on the sand and Gobi deserts was carried out, and long-term field observations and experimental stations were established to investigate engineering and vegetative management techniques for blown-sand hazards [52].

Following a 1977 desertification conference sponsored by the United Nations, the Chinese government took a more proactive approach to prevent and control desertification. Five important programs for forestry as well as desertification control were successively initiated and include the Three North Shelterbelt Development Program (3NSDP, from 1978 to 2050), the Conversion of Cropland to Forest Program (CCFP, since 1999), the Natural Forest Protection Program (NFPP, since 2000), the Sand Source Control Program in the vicinity of Beijing and Tianjin (SSCP, since 2001), and the Grazing Ban for Grassland Restoration Program (GBGRP, since 2003) [53]. Before 2010, the overall central government investment in these five key programs amounted to US$55.1 billion [53]. With the development of China's economy, a substantial increase in future investments in ecological construction and desertification control can be expected.

One of the major objectives of these programs is to mitigate overcultivation, overgrazing, and overcutting, which are the main factors triggering the desertification processes in China. Through a 32-year construction project in four successive stages since 1978, a 26.5-million-hectare afforestation area has been achieved by the 3NSDP, and the project area's forest-coverage rate increased from 5.1% to 12.4% [54]. In addition, 1.6 million hectares of windbreak and sand fixation forests were established by the fourth stage of the project (2001–2010), during which desertification began to reverse in the three northern areas, and the expansion trends of the Mu Us and Horqin sandy lands achieved full reversals [55].

The CCFP, which has paid farmers for planting of trees as opposed to crops since 1999, was a turning point in Chinese policies on agriculture and forestry. The CCFP is the largest ecological construction project financially, with the most extensive coverage and the largest amount of public participation. At the conclusion of 2009, 9.3 million ha of cropland were developed into forestland, with the area of tillage farmland significantly decreased in the farming-pastoral ecotone [55]. Soils in semi-arid areas possess a high vulnerability to water and wind erosion. Large-scale restoration of the ecology is playing a great role in the reduction of soil loss as well as sand desertification.

During stage one NFPP (2001–2010), forested regions rose by 14.0 million ha, and timber production decreased 220 million m^3 [55]. Over 6.0 million ha of cropland were reforested through the SSCP [55]. From 2003 to 2010, 518.7 million hectares of grassland were secured with fence construction through the GBGRP, 12.4 million hectares of grassland for the purpose of reversing degradation were reseeded, and vegetative coverage averages were increased from 59% to 71% [55]. The organic soil matter and biodiversity increased, and the utility of grassland for soil and water conservation, windbreaks, and sand fixation were substantially ecologically enhanced.

5.2. The Great Impact of Ecological Industrial Engineering on Sandy Desertification Control

The Sand Prevention and Control Law (SPCL) for the maintenance of ecological safety, promotion of sustainable development, and the prevention and control of desertification came in to effect in 2002. As a result, the State Council and desertified area local governments at the country level or higher must include desertification control and prevention measures with a guarantee of support in the national plans for social and economic development. Institution and individual investments in desertification control and prevention are to be treated as tax exempt as well.

The implementation of the SPCL promoted enthusiasm throughout the whole society for desertification control. Numerous green industries have been introduced to prevent and control desertification and have formed an innovative mechanism of multisource investment. The national ecological demonstration area—Engebei in Ordos, Inner Mongolia—is one of the achievements in sandy desertification governance (Figure 7). In the past thirty years, the Elion Resources Group has achieved remarkable ecological and economic outcomes in the Kubuqi Sand Desert by integrating drought-resistant afforestation and sand industry development. Alliances between companies and peasant households, state-owned as well as private companies, and industries and eco-bases have created new modes for green desert economies, such as natural pharmaceuticals and fertilizers, as well as other products.

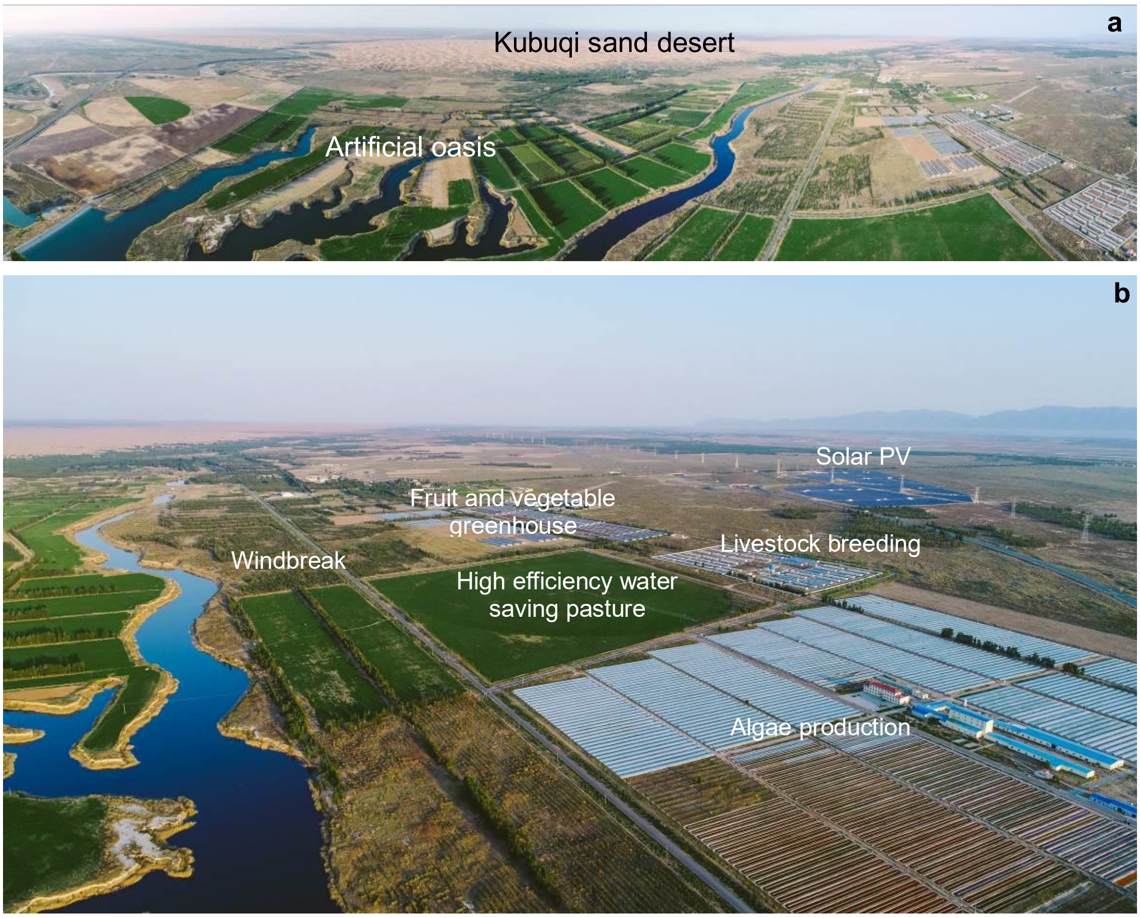

Figure 7. The national ecological demonstration area in Engebei, Ordos, Inner Mongolia. (**a**) Panorama; (**b**) sand industries. Courtesy of Liangcai Fang.

The technology for desertification control was implemented and improved (Figure 8). More than 5000 km^2 of shifting sandy land has been afforested, and over 10,000 km^2 of land are under the initial stages of control [56]. The goal of desertification mitigation aligns with interests of local residents. Benefiting from the green desert economy, the income per capita of the 100,000 residents in Kubuqi Desert increased from US$56 in 1988 to US$2000 in 2016 [57]. As the world's largest desert green economy enterprise, the Elion Resources Group proved that the new way of combining desertification control with scientific and technological progress, along with the development of ecological industries, has been effective in China and could provide valuable implications for controlling and preventing desertification for other countries.

The win-win strategy of environmental conservation motivates cooperation among governments, companies, residents, and scientists. Its goal is to accomplish both natural environment protection and livelihood improvements for the local people. Farmers receive subsidies and free training for cooperating with the local government to implement ecological restoration programs [58]. The subsidy for shrubbery in the northwestern provinces is US$428.6 hm^{-2} [59]. Studies showed that ecological programs have positive impacts on the income of households [60,61]. In the Alxa League of northern China, the local government has invested US$21.5 million in combating desertification since 2010 [62]. An increase of 14,800 ha of shrub forest was achieved by planting shrub and medicinal herbs and the agricultural income of farmers has tripled [63]. The well-being of herdsmen has improved 30.1% within 10 years, benefiting from the grassland ecological protection policy in Inner Mongolia [64].

Figure 8. Key technologies of sandy desertification control adopted by the Elion Resources Group: (**a**) Seedling greenhouse; (**b**) rabbit breeding; (**c**) *Elaeagnus angustifolia* planting; (**d**) photovoltaic agriculture; (**e**) licorice poverty alleviation; (**f**) plastic mulching cultivation of corn.

6. Discussions

During the last two decades, there have been some disputes challenging the efficiency of the desertification control programs in China. The selection of tree species lacked a sufficient scientific and practical basis during the initiation of the program. Since the 1980s, *Poplar simonii* has been planted as one of the preferred endemic species on loessial hill slopes and in sandy land areas due to its wide adaptability, fast growth, and resistance to aridity and soil infertility. This tree species displayed early adaptation to the habitat of semi-arid sandy land with flourishing vertical and lateral roots. After 20 years of growth, however, poplar wood in sandy land appeared to be declining in vitality as "small old trees" due to the excessive density, individual competition for soil nutrients and moisture, and lack of management [65,66]. The suitability of tree species for the desertification rehabilitation of dryland areas has aroused great dispute [67]. The growth, sustainability, and ecological benefits are major concerns regarding the planted vegetation, especially forest trees for alleviating sand desertification in China [68].

Since 2007, over 333 km^2 of poplar trees have died in Zhangbei, Hebei province, where 3NSDP is located, due to natural aging (30 years) and a drawdown of the groundwater level. Windbreaks in

Zhangbei have played an important role in preventing the invasion of sand and dust storms. Therefore, the poplar tree death is threatening the safety of the environment in Beijing and Tianjin. To replace the dying poplar trees with multiple forestation tree species and a reasonable structure pattern of tree species, the Zhangbei government needs to invest more than US$42.9 million. To protect existing achievements and promote desertification control, the Chinese government has implemented the second phases of SSCP (2013–2022, with an overall invested amount of US$12.5 billion), NFPP (2011–2020, with investments equal to US$31.4 billion), and GGP (2014–2020, with a complete investment of US$2.4 billion between 2014 and 2016). The grazing ban for grassland restoration has also been extended into the 13th Five-Year Plan (2016–2020). These actions create opportunities to correct the deficiencies from the first phase of the programs and improve the governance surrounding the desertification.

The Elion Resources Group implemented the Kubuqi mode of green desert economy in Xinjiang Province. The practices of Elion show that desertification control measures should suit both the local environmental conditions and the interests of local residents. Regional sustainability can be achieved through the governance of land degradation and efficient resource and industrial development. The continuous improvement of advanced science and technology for desertification control could benefit residents along "the Belt and Road", and residents of arid and semi-arid areas in other parts of the world.

China is working closely with the UNEP (United Nations Environment Programme), UNCCD (United Nations Convention to Combat Desertification), non-governmental organizations, and countries in Asia, Africa, America, etc. Various actions undertaken by the Chinese government, such as projects for green development on desertification prevention and control in Africa [69,70], China-Arab States cooperation on desertification control [71–73], the joint statement of cooperation on sustainable forest management, combating desertification, and wildlife conservation between China, South Korea, and Japan [74], and the One Belt and One Road Joint Action to Combating Desertification [75], have strengthened the international cooperation on desertification control technologies and experience.

By sharing scientific research, technologies, and policies for tackling desertification and exploring the green economy with clean energy, tourism, seedlings, breeding, planting, etc., China is putting forward tremendous efforts to enhance international cooperation. During the Kubuqi International Desert Forum in 2013, the Executive Secretary Luc Gnacadja, UNCCD signed a five-year strategic cooperation plan with the Elion Foundation to facilitate international efforts to support the green development of global deserts [76]. A long-term mechanism for cooperation among China, Pakistan, India, and Saudi Arabia was launched in 2017. China and Egypt signed the memorandum of understanding to promote the popularization and application of technologies in combating desertification in 2017 [77]. The knowledge management center for desertification control was initiated by China and UNCCD in 2019.

Training sessions and workshops were held to support the capacity-building for desertification control and prevention in Africa [78]. Since 1993, over 200 officials, experts and business leaders from more than 30 African countries have participated in training sessions organized by research institutes in China [79,80]. These training sessions focus on scientific approaches and practical methods of reversing desertification, national policies for sustainable development, and the management of land degradation [79]. Technologies, including windbreak design and maintenance, aerial seeding, plant growth and natural sand based architectural coatings, soil conservation, and water resources management, are being experimented with in Africa [80,81].

7. Conclusions

Desertification control is a challenge for the sustainable management of land. Climate change and human activities are the two key contributors to desertification and its reversal. In China, desertified area has experienced a drying and warming trend with a decrease of surface wind, a growing population, overgrazing, and deforestation in the last 60 years. Despite the complex interaction of climate change and human factors on desertification, a series of human proactive responses to desertification control led to a negative growth of desertified land. The strategy and actions of combating desertification include legislation guarantees, policies, science and technology support, national programs, green industry, multisource investments, public participation, and international cooperation.

The management areas and the investment funds of desertification control programs in China are the largest on the planet. The achievements of ecological industrial engineering in controlling desertification in China could be referenced worldwide. These practices and innovations are ongoing. Benefiting from policy and economic incentives for anti-desertification, the environmental conditions have improved, thousands of farmers and herdsmen have been lifted out of poverty, and special scientists, engineers, and government officials have been trained. Sharing the experiences and lessons gained from nearly 60 years of desertification control in China could help people in other countries suffering from desertification. Although much work is needed to achieve the sustainable development of arid and semi-arid areas across the globe, the constant exploration and innovation of desertification control is a promising path forward.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/8/3258/s1, Table S1: Population change in six provinces in arid and semiarid China.

Author Contributions: All authors contributed significantly to this manuscript. Y.L. carried out the analyses and drafted the manuscript. P.S., G.H., and L.L. participated in the design of the study and the theoretical aspects of the paper. L.G., X.H., and G.Z. were responsible for the methodology design and data analysis. All authors have read and approved the final manuscript.

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

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