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Review

Wind Erosion Induced Soil Degradation in Northern China: Status, Measures and Perspective

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Abstract: Soil degradation is one of the most serious ecological problems in the world. In arid and semi-arid northern China, soil degradation predominantly arises from wind erosion. Trends in soil degradation caused by wind erosion in northern China frequently change with human activities and climatic change. To decrease soil loss by wind erosion and enhance local ecosystems, the Chinese government has been encouraging residents to reduce wind-induced soil degradation through a series of national policies and several ecological projects, such as the Natural Forest Protection Program, the National Action Program to Combat Desertification, the "Three Norths" Shelter Forest System, the Beijing-Tianjin Sand Source Control Engineering Project, and the Grain for Green Project. All these were implemented a number of decades ago, and have thus created many land management practices and control techniques across different landscapes. These measures include conservation tillage, windbreak networks, checkerboard barriers, the Non-Watering and Tube-Protecting Planting Technique, afforestation, grassland enclosures, *etc*. As a result, the aeolian degradation of land has been controlled in many regions of arid and semiarid northern China. However, the challenge of mitigating and further reversing soil degradation caused by wind erosion still remains.

Keywords: soil degradation; wind erosion; northern China

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1. Introduction

Soil degradation is one of the most serious ecological and environmental problems facing the world [1]. In China, the total land area affected by soil degradation is approximately 861,600 km^2, accounting for 9.0% of the national territory [2]. It recognized that water erosion, wind erosion, salinization, acidification, and soil contamination are the main factors leading to soil degradation [3]. The most typical and serious form of soil degradation for China is soil erosion caused by wind or water. For arid and semi-arid northern China, the dominant soil degradation force involves aeolian processes [4]. Recently, the aeolian desertification survey of China revealed that the total area suffering from soil degradation caused by wind erosion covered 375,935.5 km^2 by 2010, about 44.1% of the total soil degraded land in China [5].

Wind-induced soil degradation may take several forms. The first and most visible form is total removal of the topsoil from bare fields, particularly on knolls within fields. This fertile topsoil may be transported to other areas of the field, deposited along the margins of the field, or totally lost into adjacent land. A more subtle form of wind-induced soil degradation is the winnowing of the finer, more chemically active particles from the soil. These fine soil particles have high surface area to volume ratios and thus carry disproportionate amounts of soil nutrients and organic carbon with them. Fine soil particles may be carried long distances from the source fields and even deposited in the oceans where they are lost from terrestrial ecosystems. They are also key to soil water holding capacity and soil aggregation and their loss often results in a looser, drier, sandier soil surface. Thus, a negative feedback loop is formed where wind-induced soil degradation may lead to a more vulnerable soil surface. Finally, wind-blown sand in the form of dunes or sand sheets may migrate over and bury fertile farm fields and grasslands resulting in lost ecosystem productivity.

Wind-induced soil degradation significantly affects local economic, society and ecosystems sustainability. The total economic loss due to wind-induced soil degradation has been estimated to be more than 54 billion Chinese Yuan (approximately 6.8 billion U.S. dollar) per year. About 170 million residents in arid and semi-arid northern China are threatened by wind-induced soil degradation [6]. Severe soil degradation generally decreases land productivity, which may result in local poverty, malnutrition, and disease. In turn, the poverty may push residents to over-exploit local natural resources, which may further degrade local sensitive ecosystems [7]. To combat wind erosion induced soil degradation and enhance local sustainability, the government invests about 0.024% of the annual Chinese gross domestic product (GDP) to launch a series of national policies and ecological projects [8]. Consequently, many land management practices and control techniques for different landscapes have subsequently been created. These national policies coupled with local residents' efforts, have made significant achievements in combating soil degradation in China. The expanding rate of soil degradation for some typical regions (such as Horqin Sands and Mu Us Sands) is controlled [9]. However, the campaign for reversing the trend of soil degradation still needs more efforts from government officials, local residents and research in the future.

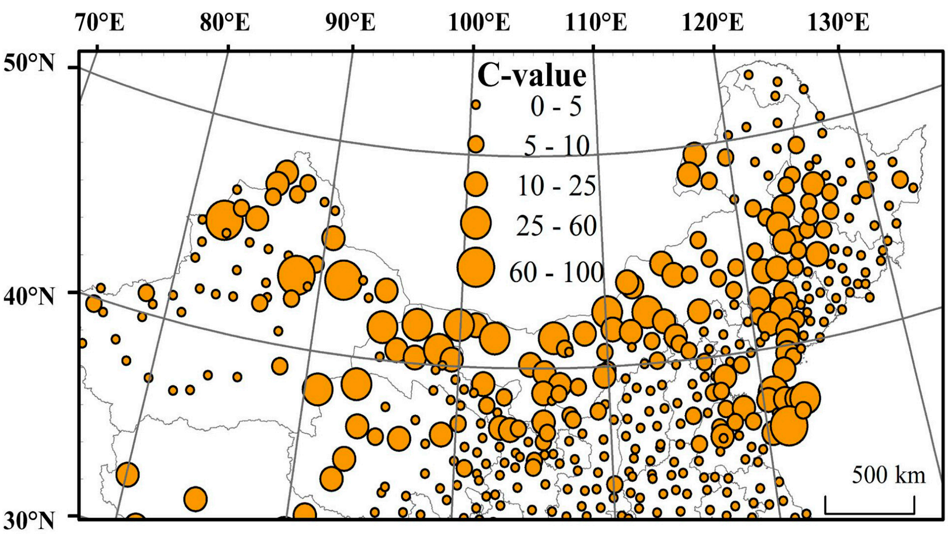
The purpose of this paper is to review Chinese processes and experiences in combating wind erosion induced soil degradation for the last 60 years. In this paper, we focus on (1) historical and current trends of wind-induced soil degradation in northern China; (2) status of typical regions suffering from wind-induced soil degradation; (3) current land management practices and problems to combat wind-induced soil degradation; and (4) perspectives on reversing wind-induced soil degradation.

2. Historical and Current Trends of Wind-Induced Soil Degradation in Northern China

2.1. Wind-Induced Soil Degradation in Northern China

In northern China, low annual precipitation (generally less than 500 mm) and strong wind between March and June are the climatic driver to wind-induced soil degradation [4]. Wind erosivity can be used to describe how the climate affects wind erosion. Many equations of wind erosivity have been proposed [10]. The C-value from the Food and Agriculture Organization (FAO) is one of the most widely-used wind erosivity indexes [4,10]. The C-value is estimated from monthly climate data (average wind speed, potential evapotranspiration, and precipitation) [10]. Figure 1 illustrates the spatial pattern of C-value for northern China. The regions with high C-value are mainly distributed in Xinjiang, Inner Mongolia, Qinghai, Ningxia, and Gansu province, with the exception of a few coastal regions (Figure 1). These dry and windy regions with high C-value are generally suffering serious wind-induced soil degradation.

Figure 1. Spatial pattern for the wind erosivity (C-value) estimated from the Food and Agriculture Organization (FAO) method in northern China.



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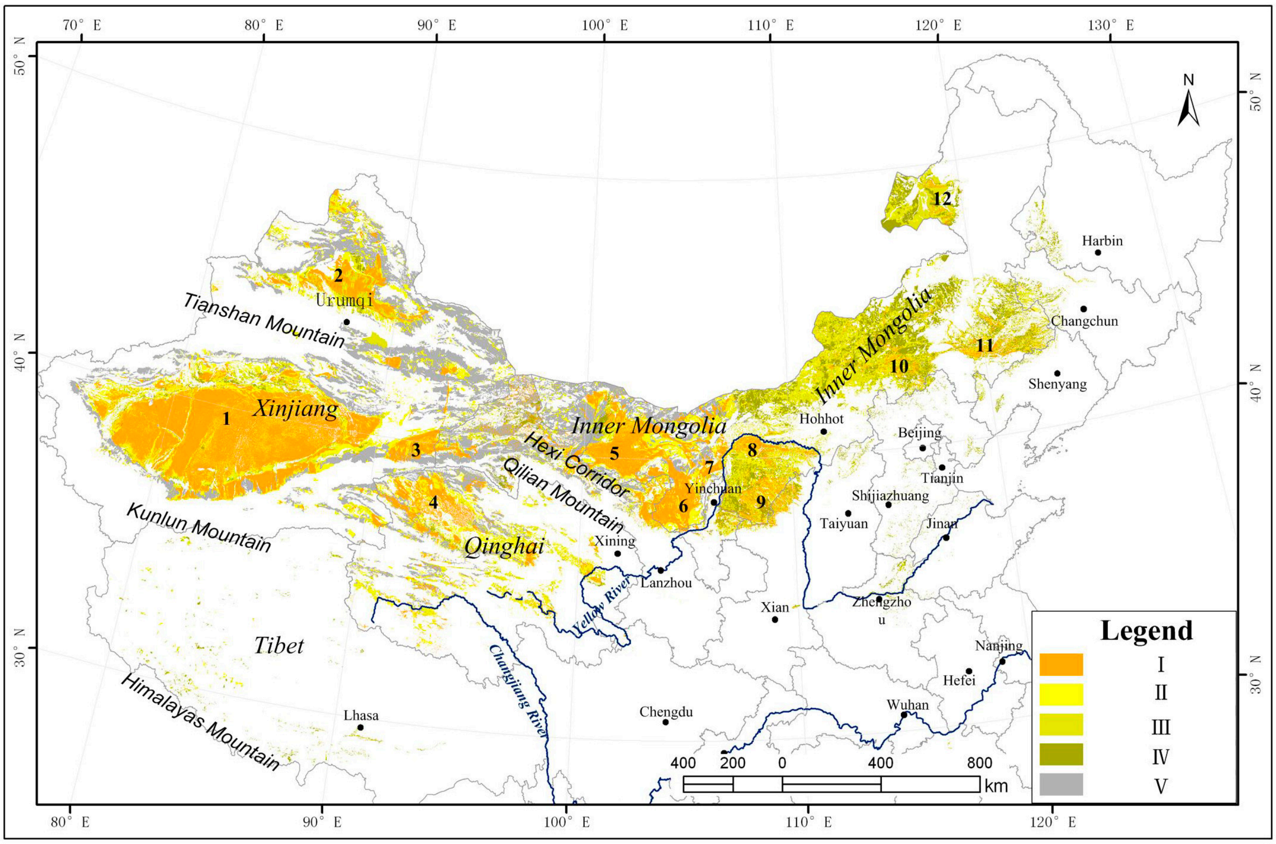
In modern China, wind-induced soil degradation mitigation efforts began in the late 1950s [11]. The first national aeolian desertified land survey was conducted in 1994 with a repeating period of five years using remote sensing, the latest survey was performed during 2009. Spatially, most land with wind-induced soil degradation (aeolian desertified land) are distributed in arid and semi-arid northern China where the annual rainfall is below 500 mm [7]. As Figure 2 shows, aeolian degraded lands are mainly scattered in (1) the semi-arid agro-pastoral ecotone of northern China (about 40.5% of total aeolian degraded land) where wind erosion and sand sheet incursions are responsible for most soil degradation; (2) the semi-arid steppe in the middle of Inner Mongolia (about 36.5% of total aeolian degraded land) where reactivation of fixed dunes and shifting sand incursions create the most soil degradation; and (3) the margins of oases and lower reaches of inland rivers in the arid region (about 23% of total aeolian degraded land) where reactivated fixed dunes cause most soil degradation [7].

Figure 2. Spatial pattern of the aeolian soil degraded land in northern China.



Notes: 1 = Taklimakan Desert, 2 = Gurbantunggut Desert, 3 = Kumtagh Desert, 4 = Qaidam Basin Desert, 5 = Badain Jaran Desert, 6 = Tengger Desert, 7 = Ulan Buh Desert, 8 = Hobq Desert, 9 = Mu Us Sandy Land, 10 = Onqin Daga Sandy Land, 11 = Horqin Sandy Land, 12 = Hulunbeir Sandy Land. I = Sandy Desert; II = aeolian degraded land with very severe and severe hazard; III = aeolian degraded land with moderate hazard; IV = aeolian degraded land with slight hazard; V = Gobi. The standard titled "Classification Standard of Sandy desertification degrees" [12] was used to classify the wind-induced land degradation hazard.

Generally, human activities are considered to be one of most important factor contributing to wind-induced soil degradation [7,12]. According to the statistics of wind-induced soil degradation in arid and semi-arid regions of northern China, over-cultivation, over-grazing, over-collecting fuel wood, inappropriate irrigation management, and engineering construction are responsible for 25.4%, 28.3%, 31.8%, 8%, and 1% of aeolian soil degraded land, respectively [7].

For the last 60 years, the trends of soil degradation caused by wind erosion in northern China frequently changed with human activities [7,12]. Table 1 presents the fluctuations of aeolian soil degradation during the last 60 years. In this paper, the standard titled "Classification Standard of Sandy desertification degrees" [12] was used to classify the wind-induced land degradation hazard, which is classified as slight, moderate, severe, or very severe (Table 2). The total area of aeolian degraded land changed from 296,470.4 km^2 to 375,935.5 km^2 between the 1950s and 2010. From the 1950s to 2000, aeolian degraded land rapidly expanded with an accelerating rate. The rates of increase for periods of the 1950s to 1975, 1975 to 1990 and 1990 to 2000 were 1560 km^2 per annum, 2100 km^2 per annum, 3600 km^2 per annum, respectively [13]. In contrast, from 2000 to 2010 the amount of aeolian-degraded land annually shrank. From 2000 to 2005 aeolian-degraded land decreased 1635.3 km^2 per annum and decreased 1114.4 km^2 per annum from 2005 to 2010. Analysis of wind-induced soil degradation spatial pattern for different period shows that variations of aeolian soil degraded land mainly occurred in the agro-pastoral ecotone of northern China [5]. In a word, wind-induced soil degradation has passed through two stages in arid and semiarid northern China. First, rapid wind-induced soil degradation occurred from the 1950s to the late 2000s. Second, wind-induced soil degradation has generally been prevented in many regions of arid and semiarid northern China by the 2010s, except for a few regions where arid-windy climate and more frequent human activities threaten the soil health (such as Bashang region, Minqin Oasis, Hexi Corridor, *etc.*) [7].

Table 1. Changes of aeolian soil degraded land from 1950s to 2010 for arid and semi-arid northern China.

Class	1950s	1975	1990	2000	2005	2010
	Area of the Class (km^2)/Percentage of Total Area for the Class (%)					
Slight	--	93,886.3/29.2	109,041.6/30.7	132,795.6/34.1	129,793.4/34	127,066.2/33.8
Moderate	--	72,525.4/22.6	81,736.7/23	89,170.5/22.9	87,120.9/22.8	85,863.7/22.8
Severe	--	76,851.7/23.9	83,477.1/23.5	85,969.2/22.1	84,086.7/22	83,307.3/22.2
Very severe	--	78,204.1/24.3	81,050.7/22.8	81,785.1/21	80,543.8/21.1	79,735.9/21.2
Total	~295,000.0	321,430.4	355,268.8	389,683.7	381,507.3	375,935.5

Notes: The data were compiled from [7] and [13]. (--) = no data; (~) = approximate data; In the 1950s, the aeolian soil degraded land survey lasted several years, thus the approximate total area of soil degradation is derived from the data in 1975 [5], and the detailed soil degradation hazard data is also not available.

Table 2. Classification Standard of Sandy desertification degrees.

Class	Percentage of Blown Sand Area (%)	Percentage of Annual Increasing Area (%)	Percentage of Vegetation Cover (%)	Percentage of Annual Reduction in Biomass (%)
Slight	<5	<1	>60	<1.5
Moderate	5–15	1–2	60–30	1.5–3.5
Severe	25–50	2–5	30–10	3.5–7.5
Very severe	>50	>5	10–0	>7.5

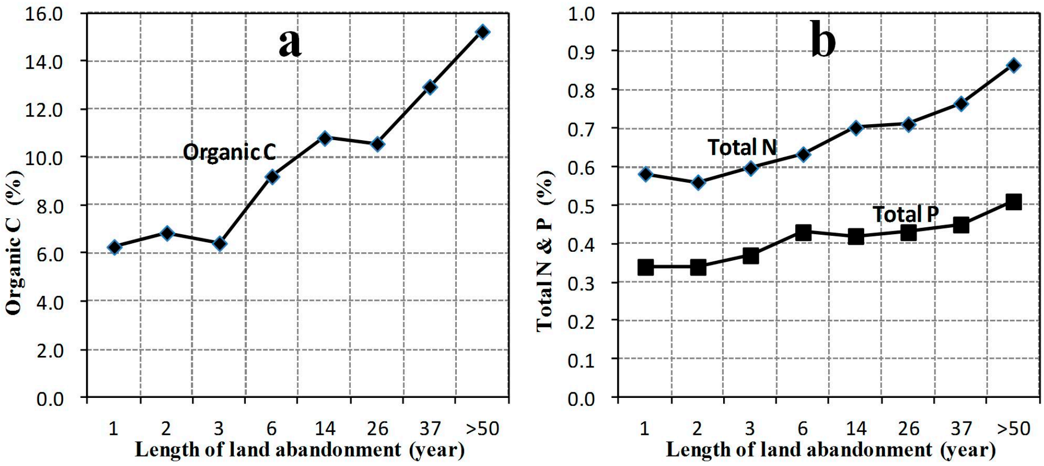
Notes: The data were obtained from [7].

2.2. Wind-Induced Soil Degradation for Typical Regions

The rain-fed agricultural region of the agro-pastoral ecotone in northern China (APEC) is a typical region suffering from wind-induced soil degradation where changes of aeolian soil degraded land mainly occurred in the APEC for last 60 years [7]. It is generally recognized that the APEC is a transitional zone including grassland and farmland, where the soil degradation is very sensitive to climate and human activities. The trends of soil degradation for different parts of the APEC differ according to the specific locality and stressors.

The Bashang region, located in the northeast part of the APEC, is a typical region where the wind-induced soil degradation is increasing due primarily to intensified human activities. The land use dramatically changed during the 20th century. The natural landscape of the Bashang region is steppe, and cultivation of steppe grassland for grain production, often leads to severe wind-induced soil degradation. The total area of aeolian degraded land changed from 2524.0 km^2 to 4608.6 km^2 between 1975 and 1987 [7]. The degraded land increased from 4608.6 km^2 in 1987 to 6970.4 km^2 in 2000 [7]. Improper tillage practices generally leads to significant soil degradation. The fine soil material carrying much of the organic C and N, and P nutrients is the first to be winnowed from the soil and lost from the landscape as fugitive dust. After eight years of cultivation, more than 50% of the soil organic C, total N, and total P had been lost from the topsoil (0–20 cm plough layer), and the nutrients decreased 60%–79% in the topsoil after 50 years of cultivation near the town of Datan in the Bashang region [14]. Soil degradation was so severe that some of the cultivated lands were abandoned. With increasing abandonment time, the soil nutrients tended to increase (Figure 3) [14]. This indicates that the soil health can be significantly improved when intensified human disturbance such as tillage is discontinued.

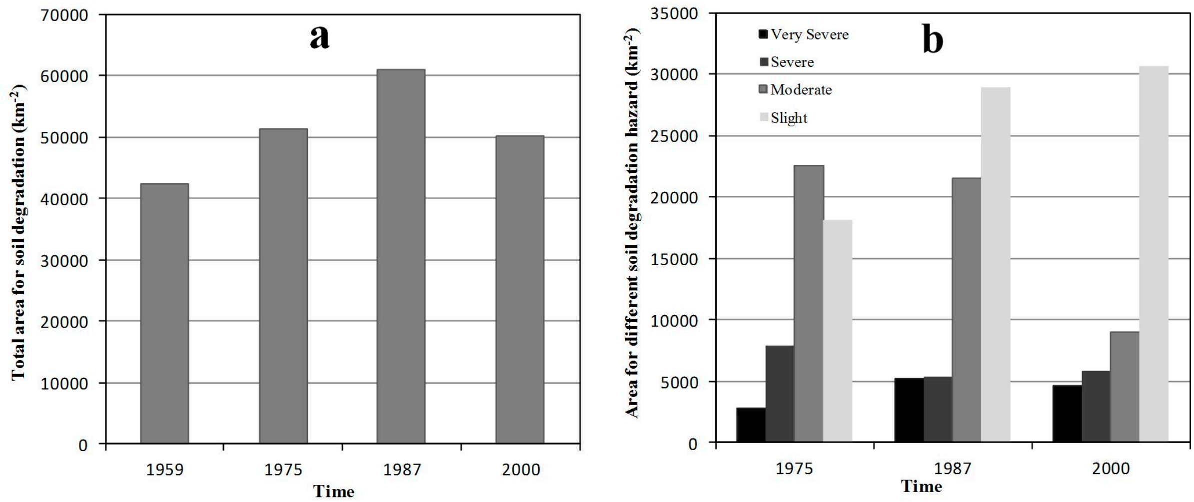
Figure 3. Soil properties affected by year of land abandonment for Datan Town in Bashang region.



Note: the data were obtained from [14].

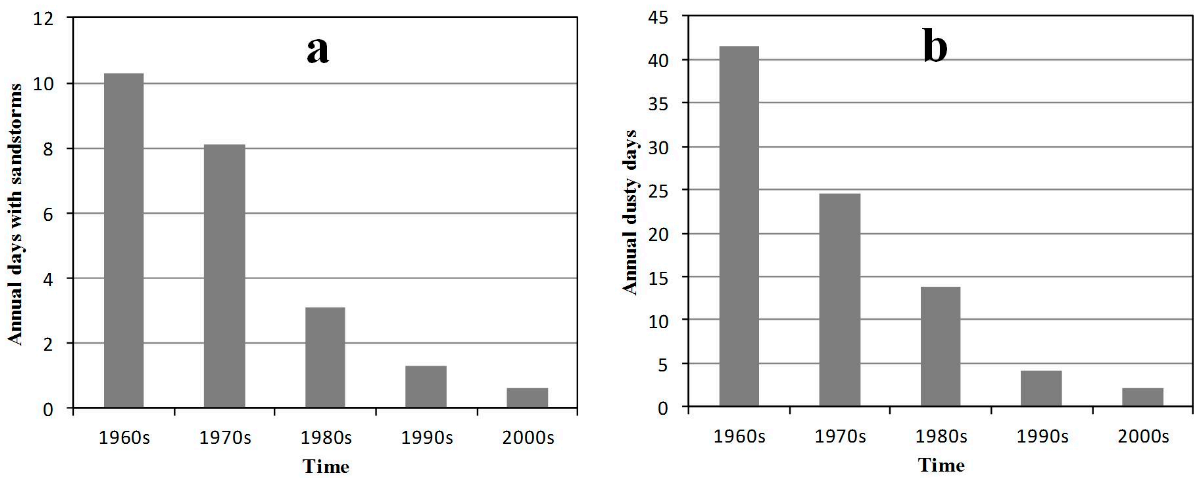
The trends of wind-induced soil degradation in the Horqin region is different from the Bashang region. Figure 4 presents the changes of aeolian degraded land in the Horqin region from 1959 to 2000. The wind-induced soil degradation accelerated in the 1970s, and decelerated in the early 1980s. Before 1987, the aeolian degraded land increased. From 1959 to 1975, the total area of aeolian degraded land area increased by 9084.0 km^2. The total area increased by 9624.0 km^2 between 1975 and 1987. After 1987, the trend of increasing wind-induced soil degradation was reversed. The total area of aeolian degraded land declined from 61,008.0 km^2 in 1987 to 50,198.0 km^2 in 2000. During this period, the total area of the severe and slightly aeolian degraded land area increased 393.0 km^2 and 1749.0 km^2, respectively, but very severe and moderate aeolian degraded land area decreased 488.0 km^2 and 12,463.0 km^2, respectively [13]. The atmospheric environment has also improved with the reductions of aeolian degraded land. Figure 5 presents the variations of the indexes of atmospheric environment for Nanman Banner (County) in the Horqin region. The annual days with sandstorm and annual dusty days gradually decreased while the annual average wind speeds fluctuated between 3.2 to 3.8 m s^{-1} from the 1960s to the 1990s (Figure 5). The reduction of soil degradation with time is generally attributed to effective comprehensive artificial measures, such as grassland restoration, afforestation, enclosures, *etc.* [15].

Figure 4. Changes of the (**a**) total area for aeolian degraded land and (**b**) area for different aeolian degraded hazard in Horqin region.



Note: the data were obtained from [13]. The data for different soil degradation hazard were unavailable for 1959.

Figure 5. Variations of the (**a**) annual days with sandstorm (**b**) annual dusty day in Naiman Banner (County) in Horqin region.



Note: the data were edited from [15]. The visibility is less than 1.0 km in the days with sandstorms, the visibility is between 1.0 and 10.0 km on dusty days.

3. Current Land Management Practices Status

To decrease soil loss by wind erosion and enhance local ecosystems, the Chinese government has been encouraging residents to reduce wind-induced soil degradation through policies, economic, and technical measures. On average, the government invests 0.024% of the Chinese gross domestic product (GDP) to mitigate wind-induced soil degradation. As a result, about 20% of the degraded lands have been controlled [8,16]. The measures for combating wind-induced soil degradation include national policies (projects) and land management practices at the field scale.

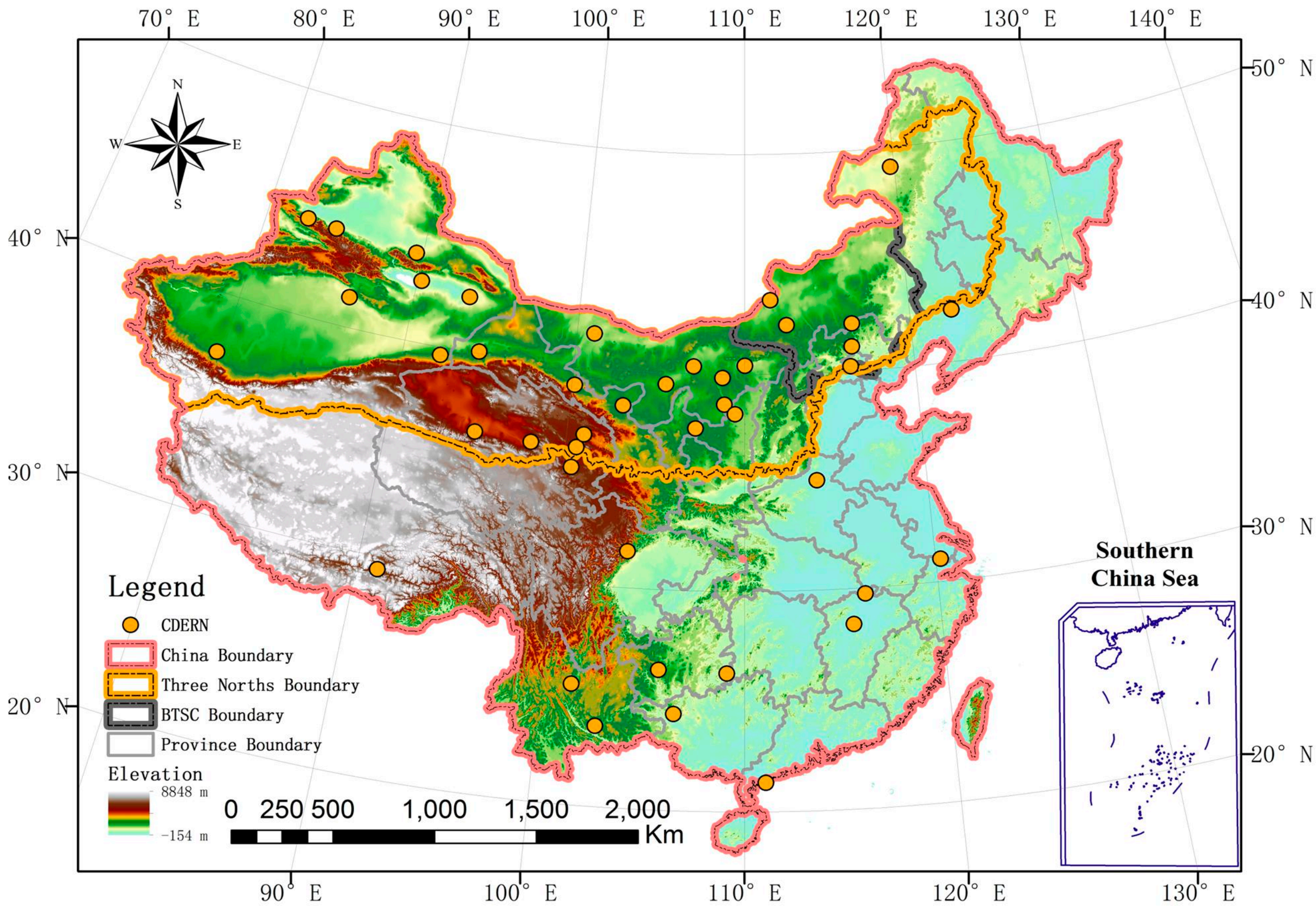
3.1. State Policy and Projects to Combat Wind-Induced Soil Degradation

To combat wind-induced soil degradation and further reverse the degradation trend, a series of state policies have been implemented. In 1994, the Chinese government signed the United Nation Convention to Combat Desertification (UNCCD) for promoting international cooperation [17]. To better implement the UNCCD, the Chinese Committee for Implementing the UNCCD (CCICCD) was organized [9]. The Natural Forest Protection Program (NFPP) and the National Action Program to Combat Desertification (NAPCD) were conducted during the late 1990s [18]. Based on these policies, the national strategic objectives to combat wind-induced soil degradation were divided into three stages: (1) a short-term objective (1996–2000) in which 3.2 million hectares of lands affected by wind erosion will be rehabilitated; (2) a mid-term objective (2001–2010) in which 7.5 million hectares of lands suffering from wind erosion will be rehabilitated; (3) a long-term objective (2011–2050) in which about 30.0 million hectares of wind eroded lands will be rehabilitated [19]. The three stages are closely interrelated and constitute a basic framework of wind-induced soil degradation control. With the implementations of these policies, the Chinese Government gradually recognized the importance of legislation for combating soil degradation and the Law of Combating Desertification (LCD) was enacted in 2002 [9]. In addition, a national monitoring system which consists of 43 research stations across China under the direction of the State Forestry Administration of China (SFA), the China Desert Ecosystem Research Network (CDERN), has been under development since 1978 (Figure 6) [17]. The national policies mentioned above are the guidelines to combat wind-induced soil degradation in China.

Meanwhile, a number of national ecological engineering projects have been launched. The Three-North (northwestern, northern, and northeastern parts of China) Shelterbelt Project (TNSP) (1979–2050), one of the most ambitious conservation programs in the world, was established to prevent soil degradation through extensive afforestation in arid and semiarid China (Figure 6) [20]. The project involves about 590 counties in 13 provinces, covering a total area of 4.1 million km^2, accounting for 42.4% of China's territory [19]. During the project period, 35.7 million hectares of afforestation is planned and the forest coverage will change from 4.0% to 16.0% for the project region [19]. From 1979 to 2010, about 27.9 million hectares of afforestation have already been implemented [19]. Another national afforestation project, the Grain for Green Project (GGP) (or named as Returning Farmlands to Grassland and Forest Project) (1999–2010), aims to return 147.0 million hectares of farmlands and 173.0 million hectares of grassland to forest between 1999 and 2010 [21]. The GGP began its pilot program in Sichuan, Shanxi and Gansu province in 1999 and finally extended to 1897 counties in 25 provinces of China [21]. By 2010, the GGP achieved its hectares goals, and the Chinese government restarted the GGP on 10

October 2014 [22]. In addition, the Beijing and Tianjin Sandstorm Source Control Project (BTSC) (2001-present) has been conducted for reducing the wind-induced soil loss and related sandstorms in the Beijing-Tianjin megacity belt [23]. The BTSC involves 75 counties in Beijing, Tianjin, Hebei, Inner Mongolia and Shanxi covering an area of 458,000 km^2 around the Beijing-Tianjin megacity belt (Figure 6). From 2001 to 2010, the first stage of BTSC has been implemented with an investment of 55.8 billion Chinese Yuan (approximately 9.1 billion U.S. dollar), with the result that 18.0 million hectares of land have been acquired and 2.6 million hectares of farmland have been afforested [24]. As to the benefit of the BTSC, the spatially average wind-induced soil loss decreased from 26.3 in 2001 to 18.7 t hm^{-2} a^{-1} in 2010 with the total vegetation coverage of the BTSC increased from 40.9% to 49.1% [23]. However, the large-scale afforestation projects did not effectively solve the local wind-induced soil degradation [25]. The overall survival rate of planting trees during afforestation projects is only 15% in the arid and semi-arid northern China [26]. This suggests that afforestation alone could not effectively reverse the trend of soil degradation. However, planting grasses or bushes may be an effective measure to curb soil degradation for some regions [25].

Figure 6. State projects to combat wind erosion induced soil degradation.



Notes: CDERN = research stations of the China Desert Ecosystem Research Network; Three Norths = northwestern, northern, and northeastern parts of China; BTSC = Beijing and Tianjin Sandstorm Source Control Project.

Additionally, many local policies, regulations, and projects have also gradually been proposed to complement or augment the state plans. These policies and projects, at different scales, offer an ongoing strategy-system to combat wind erosion induced soil degradation in China.

3.2. Current Land Management Practices Status for Different Landscape

At the field scale, the policies and projects mentioned above have yielded many typical and classical land management practices and control techniques for different landscapes. The main landscapes suffering wind-induced soil degradation are sandy land, farmland and grassland in arid and semiarid northern China.

Sandy land is most susceptible to aeolian degradation. A typical engineering measure for sandy land erosion control is the "Straw Checkerboards Barrier" (Figure 7). This technique effectively reduce wind velocity, thus lower field sand transport rate [27]. Research has revealed that the wind velocity can be reduced by 20%–40% at a height of 0.5 m and the soil surface aerodynamic roughness could increase by 400–600 times when the height of the checkerboard barriers is 0.15–0.20 m [27]. The economic and reasonable height of "Straw Checkerboards Barrier" is 0.1–0.2 m [27]. The building materials of checkerboards barrier are flexible and include straw, shrub branches, stones, clay, and artificial plastic products (Figure 7). This classical "Checkerboards Barrier" technique is still widely used in China. More recently, an ecological technique, the "None-Watering and Tube-Protecting Planting Technique for *Haloxylon ammodendron*", was invented and used for sandy land ecological recovery and restoration [28]. The planting technique uses plastic or sand-made tubes to nurse the seedlings of *Haloxylon ammodendron* based on the theory that the high temperature of sandy land surface layer (0–2 cm) (>50 °C) is one of the important ecological limiting factors [28]. After several years of testing, it was found that the technique can efficiently increase the percentage of average seedling survival by greater than 70% and annual growth rate by greater than 20% for *Haloxylon ammodendron*. In addition, the technique is also suitable for planting other sandy land plants [28].

The farmland scattered in arid and semi-arid northern China, especially farmland with bare surfaces, is another landscape undergoing soil degradation. Conservation tillage is generally considered to be an economical, practical and feasible wind erosion control method [29]. The efficacy of conservation tillage and its application for dry lands of northern China have been addressed since the 1970s [30]. Many reports have shown that conservation tillage could efficiently mitigate wind-induced soil loss at field scales even at regional scales in China [9,31]. The Chinese government has been encouraging residents to adopt applicable conversation practices since 2002 [30]. However, at a national level, the traditional cultivation practices, such as intensive tillage, residue removal or burning, are still common [30]. It may be a long time before local farmers accept and embrace conservation tillage. In contrast, windbreak networks for farmland have been gradually and steadily increasing due to the strong support of the Chinese government. As a part of the TNSP and BTSC, windbreak networks for farmland projects in arid and semiarid northern China have obtained continuous national investment. By 2008, the total area of farmland with windbreak networks was 533,300 hectares in the Three-North (northwestern, northern, and northeastern parts of China) region [19]. The effects of windbreak networks for farmland on controlling soil degradation is closely related to its porosity (density), orientation, height, width, distance between barrier rows, and length [32]. At a local scale, windbreak networks could lead to reductions of wind speed and turbulence intensity within a certain distance in the leeward and improve micro-agro-climate. At a regional scale, windbreak networks can increase terrain roughness, so a dense network has been suggested as the cause of a reduction in the average surface wind speed for the region [32,33]. Therefore, windbreak networks with optimal design is a feasible measure to combat wind erosion induced soil degradation for the farming regions in arid and semi-arid northern China where the water resource is sufficient to build and sustain windbreaks.

Figure 7. Various materials used for Checkerboards Barriers. (**a**) Straw; (**b**) Shrub branches; (**c**) Stones and Shrubs; (**d**) Plastic.

Grasslands are also very sensitive to wind-induced soil degradation in arid and semi-arid northern China. Enclosing degrading grassland to keep out grazing animals is considered to be a simple, economic and effective measure to maximize pastoral productivity and curb soil degradation, thus it is widely used in the rain-fed regions of northern China [34]. For example, an enclosed grassland significantly increased soil seed density and facilitate vegetation restoration in the Horqin region [35]. This study showed that seed density in the enclosed grassland increased by 15.7%, 482.5% and 728.1% for sites enclosed for two-year, six-year, and 12-year periods, respectively, and the vegetation coverage of the six-year and 12-year sites increased by 261.6% and 271.6%, respectively [35]. Nevertheless, some research also questioned the total regional benefit for Chinese households for grassland enclosures. Actually, enclosures generally do not decrease the number of livestock for a region. This measure could force more grazing animals from enclosed grassland to non-enclosed grassland, which may increase stocking rate of non-enclosed grassland. Investigations from Inner Mongolia revealed that grassland enclosures conducted at a village level actually increased soil degradation processes across vast territories while only protecting small isolated fields [36]. Planting grass on the degraded grassland (planted grassland) is an important measure to recover and further reconstruct the grassland ecosystem [37]. Planted grassland could also enhance pastoral productivity in a relative short time. Experiments conducted in Qaidam Basin have showed that the forage of the planted grassland could increase by 380% compared with the degraded rangeland [38]. The planted grassland generally requires tillage, fertilization, and irrigation. It is an expensive and water-consuming measure, which limits its wide use in arid and semi-arid northern China.

These measures and techniques for different landscapes are typical practical-experiences in preventing wind-induced soil degradation. Actually, the design, construction, and implementation of measures and techniques for preventing wind-induced soil degradation generally depend on local geographical features, regional soil degradation control experiences, laboratory experiments, and field observations [9]. It is still a challenge to develop and determine economical and efficient local measures or techniques for mitigating soil degradation.

4. Perspectives on Reversing Wind-Induced Soil Degradation

National policies and projects together with local land management practices and control techniques outline a blueprint to combat wind erosion induced soil degradation in arid and semi-arid northern China. Although significant progress and abundant achievements for preventing wind-induced soil degradation have been made to date, the campaign for reversing the trend of soil degradation still needs more efforts from government officials, local participants, and researchers in the future.

In China, the campaign for preventing wind-induced soil degradation involves more than 10 state ministries and administrations [14]. More time and effort is needed to coordinate these government branches to more effectively combat soil degradation. Accordingly, the government's decision-making may lag behind the development of soil degradation. Thus a powerful steering committee with a more effective institutional framework may be necessary to curb and further reverse soil degradation. The Chinese government could improve current policy in many ways. An efficient financial system with more investments has been proposed to fund the control projects and related research, and to further improve local residents' enthusiasm for combating soil degradation [39]. It is also a feasible way to explore international cooperation and funding.

The campaign for preventing wind-induced soil degradation also needs continuous research involvement and affordable control techniques. In the degradation-prone regions, an increasing local population with a resulting expanding economy makes the soil degradation and degradation reversal processes more complex. Meantime, research on soil degradation is discontinuous in northern China, which in turn decreases the locally effective tools to combat soil degradation [39]. Although it is generally recognized that vulnerable eco-environments and irrational human activities result in soil degradation, there is ongoing debate on the soil degradation process for different temporal or spatial scales [12,40]. Therefore, a series of spatially diverse long-term research projects on soil degradation are needed to support executive decision-making.

Wind-induced soil degradation is a physical, economical and social-related process [41]. Basically, executive policy and research involvement finally need to inspire local residents' initiatives. To effectively encourage local residents to combat wind-induced soil degradation, affordable technical supports to combat soil degradation and adequate economic rewards from preventing soil degradation are necessary.

5. Conclusions

Soil degradation due to wind erosion is a significant concern in arid and semi-arid northern China. The total area of lands suffering from wind-induced soil degradation was 375,935.5 km^2 in 2010. Most wind-induced degraded lands (aeolian desertified lands) are scattered in arid and semi-arid northern China where the annual rainfall is below 500 mm. For the last 60 years, the trends of soil degradation caused by wind erosion frequently changed with human activities. Changes of aeolian soil degraded land mainly occurred in the agro-pastoral ecotone of northern China. The wind-induced degraded lands increased from 1950s to 2000 but decreased between 2000 and 2010. The reductions of soil degradation are attributed to a series of state policies and projects. These policies include CCICCD (1994–present), NFPP (1998–present), NAPCD (2000-present). In light of these policies, a national strategic objectives were described by a short-term objective (1996–2000), a mid-term objective (2001–2010) and a long-term objective (2011–2050), respectively. Enaction of the LCD (2002–present) and construction of the CDERN (1978–present) were also launched. The national projects consisted of the TNSP (1979–2050), the GGP (1999–2010 and 2014–present) and the BTSC (2001–present). These national policies and projects yielded many land management practices and control techniques for different landscapes. These include conservation tillage and windbreak networks for farmland, checkerboards barrier, and the None-Watering and Tube-Protecting Planting Technique for sandy land, and planted grassland and grassland enclosures for grassland. Although progress and achievements for preventing wind-induced soil degradation have been made to date, more government officials, local residents and research efforts are still needed to reverse the trend of wind-induced soil degradation in the future.

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Author Contributions

Zobeck T.M. initiated the review paper for responding the invitation from guest editor of the special issue. Guo Z., Huang N., Dong Z., Van Pelt R.S. and Zobeck T.M. drafted the manuscript, and approved the final version.

Conflicts of Interest

The authors declare no conflict of interest.

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