Climate Change Impacts and Adaptation Strategies in Northwest China

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Abstract

Climate change resulted in changes in crop growth duration and planting structure, northward movement of planting region, and more severe plant diseases and insect pests in Northwest China. It caused earlier seeding for spring crop, later seeding for autumn crop, accelerated crop growth, and reduced mortality for winter crop. To adapt to climate change, measures such as optimization of agricultural arrangement, adjustment of planting structure, expansion of thermophilic crops, and development of water-saving agriculture have been taken. Damaging consequences of imbalance between grassland and livestock were enhanced. The deterioration trend of grassland was intensified; both grass quantity and quality declined. With overgrazing, proportions of inferior grass, weeds and poisonous weeds increased in plateau pastoral areas. Returning farmland to grazing, returning grazing to grassland, fence enclosure and artificial grassland construction have been implemented to restore the grassland vegetation, to increase the grassland coverage, to reasonably control the livestock carrying capacity, to prevent overgrazing, to keep balance between grassland and livestock, and to develop the ecological animal husbandry. In Northwest China, because the amount of regional water resources had an overall decreasing trend, there was a continuous expansion in the regional land desertification, and soil erosion was very serious. A series of measures, such as development of artificial precipitation (snow), water resources control, regional water diversion, water storage project and so on, were used effectively to respond to water deficit. It had played a certain role in controlling soil erosion by natural forest protection and returning farmland to forest and grassland. In the early 21st century, noticeable achievements had been made in prevention and control of desertification in Northwest China. The regional ecological environment has been improved obviously, and the desertification trend has shown sign of under control.

Keywords: Northwest China; climate change; impact and adaptation

1 Introduction

The Working Group II Report of the IPCC Fourth Assessment Report (AR4) [IPCC, 2007b] stated that global climate warming has had discernible impacts on many physical and biological systems, and will has long-term impacts on future natural ecology and socio-economic development. To rely on policy measures of both adaptation and mitigation could reduce the risk of climate change.

Northwest China is located in China’s inland, far away from the ocean, with drought and a scarcity of rain; its vulnerable ecological environment is sensitive and vulnerable to climate change. In the context of global warming, the regional annual mean temperature has markedly increased in Northwest China, which would inevitably affect the social and economic life in the region. Impacts of climate change on agriculture, animal husbandry, water resources, ecology and energy and other fields in Northwest China (including 4 provinces of Shaanxi, Gansu, Ningxia, and Qinghai) and strategies to adapt to climate change have been elaborated, mainly to provide scientific and technological support for adaptation to climate change for government and related industries in the region.

2 Major impacts of climate change

2.1 Impacts on agriculture

Climate change led to changes in crop growth duration and planting structure, northward movement of planting region, and more serious plant diseases and insect pests. Climate warming caused earlier seeding for spring crop, later seeding for autumn crop, accelerated crop growth, and reduced mortality for winter crop. The growth duration of wheat, corn and other determinate growth habit crops was shortened, while that of cotton, potato and other indeterminate growth habit crops was prolonged [Deng et al., 2008a; 2008b; Deng and Zhang, 2010]. Climate change also altered the regional crop planting structure. The planting pattern of predominant spring wheat changed into that of corn and cotton predominance in arid irrigated areas in Hexi Corridor. The planting pattern of spring wheat predominance changed into that of predominant winter wheat, spring wheat and potatoes in the semi-arid dry-farming areas in central Gansu. The suitable planting area for apple was expanded, but the fruit set percentage decreased due to high temperature events [Pu et al., 2009; Yang et al., 2010]. Climate warming was conducive to improving the climatic yields of cotton, rice and other thermophilic crops [Sang et al., 2006], but not for the yields of spring wheat, potatoes and other cryophilic crops. The suitable planting areas for crop were expanded northward and to high altitudes. The northern boundary of winter wheat extended 50–100 km northward, and the altitude increased by around 200 m in the eastern part of Northwest China, especially in the mountain areas of southern Ningxia by 600–800 m. The kind of crop pests increased, which affected wider area and caused more severe damages [IPCC, 2007a; 2007b; 2007c].

2.2 Impacts on animal husbandry

Damaging consequences of imbalance between grassland and livestock were enhanced. The deterioration trend of grassland was intensified; both grass quantity and quality declined; with overgrazing, proportions of inferior grass, weeds and poisonous weeds increased in the plateau pastoral areas [Li et al., 2008; Yao et al., 2007]. The growth duration of grass was prolonged, and the livestock death rate showed obvious decrease. Grasslands in Qinghai province showed an overall degradation trend from 1951 to 2000. By 2000, the moderate or severe degraded grassland areas accounted for 51.7% of the total available areas. About 50%–60% of the grassland in the Three River Source Region has shown different degradation since the 1980s. Compared with the 1950s, the yield (kg ha$^{-1}$) decreased by 30%–50%, and poisonous weeds increased by 20%–30% in the 1990s [Chen, 2007]. Vegetation coverage, grass height and productivity repre-
sented a remarkable decrease in alpine grassland at high altitude. The degradation rate of alpine meadow increased; the areas of degraded grassland were expanding; the alpine steppe community showed southward expansion \cite{Wang et al., 2005; Yan et al., 2004}. About 90% of the grassland in Gansu province degraded at the rate of 10,000 hm$^2$ per year; the degradation reached 45%; the degraded grassland area accounted for 88% of the total areas. Climate warming resulted in earlier green-up and later withering of the plateau grass, and the prolonged whole growth duration. The growth duration in most areas was prolonged by 3–5 d. The natural grazing period was prolonged. The utilization period of summer-autumn grassland was extended \cite{QCC, 2008}. In plateau pastoral areas, increased temperatures and reduced snow disasters were helpful for young stock to live over winter and spring. The livestock death rate decreased markedly. The death loss of yak and sheep in Gannan decreased respectively at the rate of 0.99% and 2.74% per decade. Since the mid-1980s, survival rate of the Tibetan sheep lamb has increased at 7.19% per decade \cite{Deng et al., 2008b; Yao et al., 2007; Chen, 2007}.

2.3 Impacts on water resources

In Northwest China, the amount of regional water resources generally had a decreasing trend, and has recovered slightly since 2000. The runoff of the upper Yellow River and the upper Yangtze River decreased significantly from 1961 to 2007. Compared with the 1980s, the average annual flow of the upper Yangtze River, the upper Yellow River and the upper Lancang River decreased by 24%, 27% and 13% respectively in the 1990s. The average annual flow of the upper Yellow River decreased at the rate of 5.29 m$^3$ s$^{-1}$ per decade from 1961 to 2009. The flow reduced by 206.8 m$^3$ s$^{-1}$ which was a reduction of 32% in the 1990s \cite{QCC, 2008}.

The peat swamp land in the Three River Source Region was dried and bare. The low humid meadow vegetation changed to mid-xeric alpine vegetation. The vegetation biomass decreased. The function of wetland was weakening. The swamp wetland in source region of the Yellow River was 389,000 hm$^2$ in the early 1980s, and reduced to 325,000 hm$^2$ in the 1990s at an average decrease rate of 5,900 hm$^2$ per year. It reduced by nearly 200 km$^2$ for 1990–2004, and the reduction was especially remarkable \cite{Li et al., 2009}. The wetland in the upper Yangtze River also showed a degradation trend. The Yushu Longbao wetland reduced at the rate of 487.3 hm$^2$ per year. Although the annual precipitation in the Qinghai Lake Basin had a slight increasing trend, the inflow reduced as the temperature rose. From the 1960s to the end of the 20th century, the water level of the Qinghai Lake declined about 3.37 m at the rate of 0.84 m per decade \cite{Liu, 2001}.

However, in recent years the control over the degradation of wetland in the Three River Source Region had shown initial success. The lake wetland in the source region of the Yellow River continuously increased both in area and quantity from 2003 to 2006. The area increased from 1,462.94 km$^2$ in 2003 to 1,594.79 km$^2$ in 2006, and the number increased from 71 in 2003 to 162 in 2006. The wetland area in the source region of the Yangtze River had an overall increasing trend in recent 10 years. It increased by 332.65 km$^2$ from 1990 to 2004 at an average rate of 23.76 km$^2$ per year \cite{Li et al., 2009}.

Since 2003, precipitation in the upper Yellow River has been increasing continuously, and the flow has also increased. The average flow of the upper Yellow River reached 604.7 m$^3$ s$^{-1}$ in 2003–2009, and increased by 81.4 m$^3$ s$^{-1}$ (15.6%) compared with 1991–2002. Runoff of the source region of the Yangtze River also experienced the same variation. It reached the bottom in the 1990s. Precipitation in that region has had obvious increase since 2000. The annual flow of the upper Yangtze River reached 500.9 m$^3$ s$^{-1}$ in 2003–2009, and increased by 137.8 m$^3$ s$^{-1}$ (37.9%) compared to 1991–2002 \cite{QCC, 2008}. At the same time, the inflow runoff of the Qinghai Lake increased due to precipitation increase since 2004. The water level of the Qinghai Lake began to rise in 2004, and rose by 55 cm in 2004–2009. The Lake area increased from 4,254.38 km$^2$ in September 2004 to 4,323.2 km$^2$ in September 2009. Similar variations of water level
and area were seen in the Hala Lake, Zhaling Lake and Eling Lake; both water levels and areas of these lakes have showed an increasing trend since 2005 [Wu et al., 2008].

2.4 Land desertification

Since the 1970s, there has been a continuous increase in desertification expansion. Increase of water demand in agricultural irrigation areas and farmlands due to climate warming, indirectly resulted in natural ecosystem degradation, and accelerated the regional surface desertification [Xu et al., 2007]. As for land desertification along the Great Wall in northern Shaanxi province, there was a land area of 293.5 km² becoming desert in 1986–2000. Among these new desertification lands, the largest increase occurred in Shennu county, accounted for 23% of the desertification area. The desertification mainly occurred in arable land, grassland and woodland. Grassland desertification was extremely severe and arable land desertification was moderate. For the new desertification land, arable land desertification was principle, followed by grassland and woodland, accounted for 63.89%, 25.68% and 7.68% respectively of the new desertification land [Gao et al., 2005]. The desertification land was 5,960,000 hm² in Qinghai province in 1959. It increased to 9,575,000 hm² in the mid-1980s, 12,558,000 hm² in the mid-1990s, and reached the peak of 22,200,000 hm² in 2000 [QCC, 2008].

2.5 Soil erosion

The regional soil erosion in Northwest China was very serious. Soil erosion area accounted for more than 2/3 of the total area. The second general survey data of the land in 2005 showed that the soil erosion area was 123,600 km² in Shaanxi province, and accounted for 60% of the provincial land area. The annual average sediment discharge was 920 Mt, accounted for 1/5 of total soil erosion in China. The Yellow River Basin was the most serious soil erosion area. For the Jinghe, North Luohe, and Weihe Rivers, located in the Middle Yellow River with total area of 135,600 km², the soil erosion area was 101,000 km², and the annual sediment discharge was 830 Mt [Wang, 2008].

3 Adaptation to climate change

3.1 Agriculture

Climate warming condition increases heat energy resources and prolongs the available growing season, which results in the higher multiple crop index, favorable conditions for multiple cropping system and agricultural carbon sequestration [Qu, 2010]. The interplanting of spring wheat and corn gradually changed to multiple cropping of winter wheat and corn, or winter wheat and early-maturing transplanting rice in Ningxia [Zhang et al., 2008]. To adapt to the warm and dry climate, optimization of agricultural arrangement and adjustment of planting structure have been carried out. The planting area and proportion of winter wheat and other winter crops and cotton and other thermophilic crops should be enlarged appropriately, while the planting area of spring wheat and other cryophilic crops should be reduced. It’s very beneficial to expand thermophilic crops in oasis irrigation agriculture areas. For example, cotton planting areas showed a gradually expanding trend in Hexi Corridor of Gansu province. The suitable area increased from 1,300 km² to 1,400 km². Reducing spring wheat area, expanding winter wheat and winter oilseed rape growing area, and expanding drought tolerant crop area, such as potato, millet, P. miliaceum, flax and so on, are good in dry-farming areas [Deng et al., 2008a; 2008b; Deng and Zhang, 2010]. The planting areas of millet, P. miliaceum, beans, buckwheat and other minor grain crops, which are able to bear drought, cold, and barren, were expanded in northern Shaanxi province [Zhang et al., 2007]. At the same time, the resistant varieties such as potato, flax, and beans, which have strong capability to resist drought, water-logging, high (low) temperature and plant diseases and insect pests, were cultivated more [Ma et al., 2004]. Water-saving agriculture has been developed rapidly within the region to improve the agricultural water-use efficiency. For example in semi-arid and semi-humid climatic regions, application of water harvesting and water-saving irrigation was of universal significance in areas with annual precipitation of 300–800 mm, and even more significant benefits could
be obtained in areas with annual precipitation of 400–700 mm [Deng et al., 2008a; 2008b; Deng and Zhang, 2010], where 1/3–1/2 of rainfall runoff can be collected for irrigation. In case of serious spring drought, the benefit of applying film mulching technology to preserve soil moisture, to protect seedlings and to increase production was significant, especially in dry year when sowing was impossible due to low soil moisture. For example, the average yield of mulched corn per mu (1 mu=667 m$^2$) could increase by 88.3% than uncovered corn [Chen, 2001; Deng et al., 2003; 2004]. Potato production could increase by over 30% compared with the open cultivation in dry-farming areas [Lu, 2008]. Solar light and heat resources were sufficiently utilized to break the regional and seasonal natural limit of traditional agriculture and to develop facility agriculture [Chen et al., 2002].

3.2 Animal husbandry

Ecological animal husbandry was developed to promote the balance between grassland and livestock. To restore the grassland vegetation, to increase the grassland coverage, to reasonably control the livestock carrying capacity, and to prevent overgrazing, measures such as returning farmland to grazing, returning grazing to grassland, fence enclosure and artificial grassland construction had been implemented. Establishment of the Three River Source Natural Reserve and large-scale implementation of ecological environment protection and construction projects since 2003, grassland ecological community productivity and vegetation coverage have showed a significant increasing trend. In general, the grass coverage, height and yield have increased year by year. Grassland ecosystem has an obvious trend toward restoration. Grassland with middle or high coverage in the Three River Source Region increased yearly from 2003 to 2009. In particular, grassland with high coverage increased significantly. It increased by 3,613,200 hm$^2$ in 2009 compared with the average of 2003–2008. At the same time, grassland with high yield also showed a significant increasing trend. Grassland with yield of 400–500 or 500–600 kg per mu increased by 200% and 130% respectively in 2009 compared to 2008. The average yield of fresh grass of natural grassland in Qinghai province was 2,388.93 kg hm$^{-2}$ in 2009, with an increase of 0.7% than 2008 [QCC, 2008]. In source region of the Yellow River, vegetation height increased by 22.19%, vegetation coverage increased by 17.32%–23.43%, and the yield increased by 9.98%–24.38%. The proportion of grasses and sedges increased and that of weeds decreased in the community [Nie et al., 2008]. It is worth mentioning that, since the implementation of returning grazing to grassland in meadow grassland of Gannan in 2004, vegetation coverage has increased from 60% to 75% on average. After enclosure in natural grassland of Yanchi, the grassland vegetation coverage, height, yield and density increased in different degrees, and the livestock carrying capacity also increased [Ma and Wang, 2004]. The grass composition changed significantly due to fence enclosure. Species and yields of good Cyperaceae and Gramineae increased, and those of weeds decreased [Du and Zhang, 2007]. The implementation of breeding in pastoral areas, fattening in agricultural areas, seeding in agricultural areas and supplementary feeding in pastoral areas made the new animal husbandry development pattern of complementary resources among pastoral areas, agricultural areas and half pastoral farming areas become reality. By 2006, the total area of grassland rodents control was 35,706,000 hm$^2$ in Qinghai province for the past 40 years. The vegetation coverage recovered to 40%–90% after killing and preventing the rodents. Increased forage quantity not only restored the grassland vegetation, but also greatly alleviated the pressure of natural grassland grazing, as a result, the grassland productivity rose by a large magnitude [An, 2008]. After deratization and deinsec-tization, the grassland vegetation gradually restored in Qinghai province, and the grass yield increased by 1,487,600–2,479,300 t per year, equivalent to the annual forage quantity of 815,100–1,358,500 sheep. By preliminary estimation, repairable grassland ecosystem service value reached up to $80,213,000 each year due to ecological restoration [Cai, 2006].

3.3 Water resources

A series of measures, such as development of ar-
Artificial precipitation (snow), water resources control, regional water diversion, and water storage project, were used effectively to mitigate the impact of climate change on water resources. Artificial precipitation (snow) was the main way to exploit cloud water resources, and played an active role in improving the situation of water shortage. Rainfall increased by 11,563 million m$^3$ in the Three River Source Region during the artificial precipitation period of 2007–2008. The cumulative area of aircraft precipitation (snow) operation was 1,560,000 km$^2$, and surface rainfall increased by 4,350 Mt in Shaanxi province in 2003–2008 [SWMO, 2010]. The assessment of artificial precipitation effect showed that the rainfall increased by 21.5%. From 2003 to 2008, 20.85 million RMB was used directly for artificial precipitation, and the direct economic benefits was 2,610 million RMB (increased precipitation was converted to 0.6 RMB each ton). The cumulative operation area was about 8,378,000 km$^2$, and the cumulative rainfall increase was 7,219 Mt in Ningxia from 1988 to 2008. An economic benefit of about 1,060 million RMB was created, and the input-output ratio was 1:25.

In view of the increasingly serious ecosystem deterioration in the Heihe River Basin and prominent conflicts about water allocation, a unified dispatch of water resources was implemented at the end of 1999. Five years later, a significant change in temporal and spatial distribution of water resources in the basin occurred. The discharged water at the middle reaches of the river increased every year. According to the water allocation curve for the Heihe River, when the annual inflow of Yingluo Gorge was 1,580 million m$^3$, the outflow of Zhengyi Gorge increased from 730 million m$^3$ (1997–1999 mean before the dispatch implementation) to 800, 830, 900, and 950 million m$^3$ respectively from 2000 to 2003. Water in the Heihe River reached Bukhen-Torei, capital of Ejina Banner in 2001. In 2002, the water ran into the East Juyanhai Lake which had dried up for 10 years. The maximum water area of the East Juyanhai Lake reached 23.5 km$^2$. In 2003, the water entered the West Juyanhai Lake that had dried up for 40 years. The water has been transferred to the East Juyanhai Lake for 10 times since 2002. From August 20, 2004 to April 17, 2006, the East Juyanhai Lake was not dry for 605 consecutive days. When a certain amount of water was kept in the East Juyanhai Lake for a long time, groundwater in the lake areas was effectively supplemented, where the biological diversity increased significantly and the ecological environment was gradually restored [Qiao et al., 2007]. The Taohe River is the great first tributary of the upper Yellow River. The Taohe River water was transferred to the central region of Gansu province, which benefited total area of 19,700 km$^2$ and total population of about 3 million people. Conflict over water resources arising from the imbalance between supply and demand in the central arid region of Gansu province represented by Dingxi was solved fundamentally [Liu et al., 2009; Wang, 2003; Yan, 2005]. Water from the Yellow River is the main agricultural water in Ningxia province and water-saving irrigation has been popularized since 1998 [Peng et al., 2006; Xu et al., 2004; Kang, 2005; Yang, 2004]. The water-saving irrigation control technology for rice field saved water at 404 m$^3$ per mu (31.4%–43.5%). By 2006, the water-saving irrigation area had reached an accumulative total of 213,800 hm$^2$. The annual water transfer out of the Yellow River decreased from 8,860 million m$^3$ in 1999 to 6,845 million m$^3$ in 2006, with a decrease area of 13,000 hm$^2$.

3.4 Soil erosion

In Northwest China, natural forest was very rare but played a very important role in inhibition of soil and water loss, soil erosion control, water conservation, adjusting river flow, and reducing natural disasters in the local and downstream areas. With the overall start of national natural forest protection project in Gansu province in September 1998, public welfare forest construction of 10.7 million mu had been completed by 2008. Among them, artificial afforestation, aerial seeding afforestation and closed forest were 2.2, 1.68, and 6.82 million mu respectively, which was equivalent to 52.12 Mt of carbon dioxide absorbed. Water conservation and ecological functions were significantly enhanced. The area affected by soil erosion continuously decreased, and the intensity of soil erosion also decreased year by year [Zhao, 2007; Guan et al., 2006;
Yang and Yang, 2006]. Noticeable results were achieved in controlling grassland desertification, rodents and black soil patch by the implementation of ecological protection in 2007 in the ecological function areas of Gannan where the Yellow River is the main water supply [Ge, 2009]. By the end of March 2003, an area of 2,724.9 km$^2$ affected by soil erosion had been controlled. Annual average soil erosion modulus decreased from 335–568 t km$^{-2}$ to 200–500 t km$^{-2}$.

In recent years, the soil erosion control became more powerful. Returning farmland to forest and grassland played an important role in improving the vegetation coverage and reducing slope erosion. In addition, decreased strong wind days and wind speed reduced the wind force to soil erosion. Increased precipitation slowed down the vegetation degradation trend, which had a certain controlling effect on soil erosion. The areas affected by soil erosion had been obviously controlled under a wide-range popularization of integrated management projects in small watersheds. Accumulative total area of 75,000 km$^2$ affected by soil erosion was dealt with just in Gansu province in recent years. The control area was 48% in Gansu of the Yellow River Basin. By the end of 2009, in Qinghai province accumulative total area of 812.32 km$^2$ affected by soil erosion had been dealt with. Compared to 2000, area affected by water erosion and wind erosion in the Three River Source Region decreased by 3,309.08 km$^2$ (1.3%) and 1,369.8 km$^2$ (0.5%) respectively [QCC, 2008].

3.5 Land desertification

In the early 21st century, noticeable achievements have been made in desertification control and prevention in Northwest China. The regional ecological environment has been improved obviously, and the desertification trend has seemed to be under control. The protection system based on building windbreak and covering materials along the leading edge of the Tengger Desert in Zhongwei of Ningxia was established. In the 1970s, afforestation for sand control and establishment of shelter forest or net were carried out on both sides of the North Trunk Canal along the edge of the desert. By the mid-1980s, the protection system of five zones in one formed within the protection zone, which effectively controlled and prevented mobile dunes from moving southward [Sun et al., 2003]. In 2006, the third national desertification monitoring results showed that a total desertification land of 467,000 km$^2$ had been governed in Ningxia. The desertification land and sandy areas were decreased by 233,000 km$^2$ and 25,400 km$^2$ respectively compared to 1999. Ningxia became the first province in which the control speed was faster than the desertification expansion speed in China. Its ecological construction entered a new stage of overall containment and partial improvement. There had been a reversal of the desertification process which can be described as human advances and desert recedes [Jing, 2008]. By aerial seeding afforestation and planting grass, large areas of desertification prevention and control in Maowusu sandy land in Yulin of Shaanxi province had also achieved great success. The Psammophyte planting mode was adopted to control the sand outlet and the mobile dunes areas and reduce wind speed, which had achieved good results for wind-prevention and sand-fixation in Gansu province. In the early 21st century, because of increased precipitation in some areas and vigorously implementation of the ecological deteriorated land control construction, the desertification trend slowed down in Northwest China and there was even a reversal in some areas. The desertification area reduced to 12.6 million km$^2$ in Qinghai in 2009, reaching the level of the mid-1990s. In Gonghe, Xinghai, and Haiyan, the dune height reduced by 0.1–1.0 m compared to the average of 2004–2007; the dune horizontal movement speed reduced at 2.5–12.2 m per year compared to the average speed of 2003–2008. The desertification areas reduced by 83,600 km$^2$ in Gansu province in 2004 compared to that of 1999.

4 Conclusions

(1) Climate change resulted in changes in crop growth duration and planting structure, planting region moving northward, and more serious plant diseases and insect pests. Climate warming caused earlier seeding for spring crop, later seeding for autumn crop, accelerated crop growth, and reduced mortality
for winter crop. The growth duration of determinate growth habit crop was shortened, while that of indeterminate growth habit crop was prolonged. To adapt to the warm and dry climate, optimization of agricultural arrangement and adjustment of planting structure had been carried out.

(2) Damaging consequences of imbalance between grassland and livestock were aggravated in some areas. The grassland deterioration trend was intensified; both grass quantity and quality declined; with overgrazing, proportions of inferior grass, weeds and poisonous weeds increased in the plateau pastoral areas. The grass growth duration was prolonged, and the livestock death rate decreased obviously. Measures such as returning farmland to grazing, returning grazing to grassland, fence enclosure and artificial grassland construction had been implemented to restore the grassland vegetation, to increase the grassland coverage, to reasonably control the livestock carrying capacity, and to prevent overgrazing.

(3) The amount of regional water resources had a general decreasing trend in Northwest China. A series of measures, such as development of artificial precipitation (snow), water resources control, regional water diversion, water storage project and so on, were used to deal with the negative effects of climate change.

(4) Increases in agricultural irrigation area and farmland water demand caused by climate warming, indirectly resulted in natural ecosystem degradation, and accelerated the regional surface desertification. In the early 21st century, noticeable achievements have been made in desertification control and prevention in Northwest China. The regional ecological environment has shown noticeable improvements, and the desertification trend has seemed to be under control.

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