African Journal of Agricultural Research Vol. 6(7), pp. 1707-1716, 4 April, 2011
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR10.686
ISSN 1991-637X ©2011 Academic Journals

Full Length Research Paper

Remote sensing-based temporal-spatial variability of desertification and driving forces in an agro-pastoral transitional zone of Northern Shaanxi Province, China

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Accepted 21 January, 2011

Desertification has been widely treated as one of the major environmental hazards in the world by scientific communities and the public. In order to assess temporal-spatial variability of desertification from 1986 through 1993 to 2003 in an agro-pastoral transitional zone of northern Shaanxi, China, satellite images were interpreted and analyzed along with meteorological and socio-economic data. During the intervening 17-year period, desertification has decreased in severity and increased in extent. Temporally, severe desertification has decreased in area by 26.8% from 1986 to 2003. Desertification landscape patch quantities and fragmentation indexes have increased gradually. Spatially, desertification has increased in extent north of the Great Wall and decreased in extent in the Wudao river valley and north-western Shenmu County. The geographic centers of deserts in the study area have moved to the south-west and north-east. Climate change and human activities were somewhat responsible for the decrease in desertification severity but significantly affected the increase in desertification extent. The "Three north shelterbelt program" and "grain-for-green project" carried out by the governments were the dominant contributors to the desertification severity reversal. Desertification control is a difficult and gradually process and the government should continue to play a leading role in this process.

Key words: Desertification, spatio-temporal variation, landscape patch quantities, geographic centers, agro-pastoral transitional zone.

INTRODUCTION

Increasingly, human activities are changing the natural ecology and environment of the planet. One such change, desertification, is widely recognized as one of the most critical environmental hazards (Zhu and Liu, 1981; Mainguet, 1991; Zhu and Chen, 1994; Luo, 2003; Liu and Diamond, 2005). The increasing rate of desertification implies a clear manifestation of human influenced, climatic-changing processes on the environment (Collado et al., 2002). There is an increasing need for research into the dynamics and causes of desertification to provide important instruction for desertification control strategies and rational planning of land use in arid and semi-arid areas (Wu, 2002). Therefore, considerable research and numerous studies have been devoted to desertification assessment and monitoring. Additionally, this research has informed policy-makers and raised awareness among the public.

In the study of desertification, many researchers have focused on monitoring trends in land degradation and identifying and characterizing sand dunes and their temporal dynamism in arid, semi-arid, and agriculturally productive areas in the world. Tucker et al. (1991) reported the expansion and contraction of the Sahara Desert from 1980 to 1990. Hanafi and Jauffret (2008) assessed the desertification processes based on vegetation dynamics from 1975 to 2000 in the arid steppe of southern Tunisia. Rasmussen et al. (2001) observed the desertification reversion in northern Burkina Faso from 1955 to 1994. As one of the several countries severely affected by desertification, where desert land totals 2.62 million km^2, approximately 27.3% of the territory, and is

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mainly distributed in the north, more attention have been given to the dynamics of desertification in China.

Many researchers have compared the status of typical desert areas in different years, such as in the Longyangxia Reservoir from 1975 to 2005 (Yan et al., 2009), in Minqin County from 1985 to 1997 (Sun et al., 2006), in Inner Mongolia from 1992 to 1996 (Zhao et al., 2005) and over the past 30 years (Yang et al., 2007), in the Mu Us Desert in the historical period (Huang et al., 2009) and from 1950s to 1990s (Wu and Ci, 2002), and on the Otindag sandy land from 1987 through 2000 to 2006 (Liu et al., 2008). Monitoring the dynamics of desertification is essential to enforce policy to control land degeneration. However, few integrated analyses of desertification development and its causes have been undertaken (Wu and Ci, 2002).

Desertification has been defined as land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities (INCD, 1994). Unfortunately, no consensus has been reached regarding the exact role of these two factors (Mainguet and Da Silva, 1998; Sun et al., 2006). Natural variables played a major role in historic desertification analysis (Sun, 2006), but seemingly, anthropogenic factors were prior to natural factors regarding desertification variation, as pointed out by many studies. Improper agricultural practices, overgrazing, mining, fire management schemes, recreation practices, deforestation, urbanization, and the introduction of exotic species have been suggested as contributing factors of desertification in the United States (Mcclure, 1998).

Rapid population increase, severe soil erosion, deforestation, low vegetative cover, and unbalanced crop and livestock production have been suggested as contributing factors of land desertification in Thiopia (Girma, 2001). The main causes of desertification in the Mu Us Desert seem to be intensified and irrational human activities, such as over-reclaiming, over-grazing, and over-cutting (Wu and Ci, 2002). Increasingly, human population pressure and rapidly economic development has shown to be the leading cause of desertification (Darkoh, 1998; Ayoub, 1998; Liu and Ci, 2000). Although there are many successful model projects to combat desertification and a long-standing governmental commitment, land desertification in China has become worse and turned into a major impediment to economic development in desert regions (Wu and Ci, 2002). With increasing population pressure and rapidly changing land use since the 1980’s, severe desertification has become an increasingly serious issue in arid and semi-arid regions of China.

Since the 1990’s, which were marked by a stark increase in sand storms, many projects to control desertification were initiated and many desert areas, such as in Ningxia, Qinghai, Inner Mongolia, Gansu, and Shaanxi, have been controlled, but the controlled areas are small and localized and are easily reversed by human activities and rapid economic development. Therefore, these fragile areas, which are subject to development pressures, need to be strictly monitored. Since the 1990’s, a project to control desertification, the “three north shelterbelt program”, has been implemented and a sand control station has been constructed. Meanwhile, rich coal and petrol resources have been exploited, which has brought economic prosperity to the region. Therefore, the desert areas of northern Shaanxi are a sensitive topic in regards to desertification research due to the conflict between desertification control measures and resource exploration.

Research concerning the formation and evolution of deserts, the effects of resource exploitation on sandy soil, and the management and utilization of the farmland provides a solid background for further research in this area, however, few studies on desertification in this sensitive area provides an integrated assessment of the spatial and temporal dynamics and driving forces. The objectives of this paper are to:

(1) Monitor the temporal and spatial dynamics of desertification from 1986 to 2003 in the sensitive area of an agro-pastoral transitional zone of northern Shaanxi province, China, and
(2) Identify any potential causal factors associated with spatio-temporal changes in desertification risk.

This study intends to provide useful information for controlling and managing desertification in the area. It is hoped that through a better understanding of desertification risk at the community level, a better set of corrective actions and policies can be put in place.

MATERIALS AND METHODS

Study area

The study area is located in Shaanxi Province in northwest China (ranging from 107°35′ to 111°29′E and from 37°35′ to 39°02′N) with an approximate area of 36,136 km^2 (Figure 1). The desert areas of northern Shaanxi Province lie in an agro-pastoral transitional zone. Elevation in the region ranges from 800 to 1800 m, sloping generally downwards from the northwest to the southeast. The Mu Us Desert lies to the north and a Loess plateau lies to the south. The area has a typical continental semi-arid climate and the annual average temperature is about 7.0 to 9.0°C with monthly mean temperatures of 24°C in July and -8.5°C in January. The accumulated active temperature ≥ 0°C is 3524 to 4541°C and ≥ 10°C is 2847 to 4147°C. Mean annual precipitation in the area is 250 to 450 mm, 70% of which is concentrated between June and September. Annual average evaporation is 1152 to 1290 mm, or 3 to 5 times annual mean precipitation. Over 150 days have wind speeds of more than 5 m s^{-1}.

The main vegetative cover type is sandy grassland, which covers more than 80% of the desert area and *Artemisia Ordosica* is a dominant species. Other natural vegetative cover types include meadows and shrubs. In addition, there is farmland distributed along the river and interspersed with sandy grassland and artificial forests and shrubs (Department of Geography of Peking University, 1983; Zhang, 1994). Arid agriculture is the dominant land use type in the west (Dingbian and Jingbian), and semi-arid agriculture and

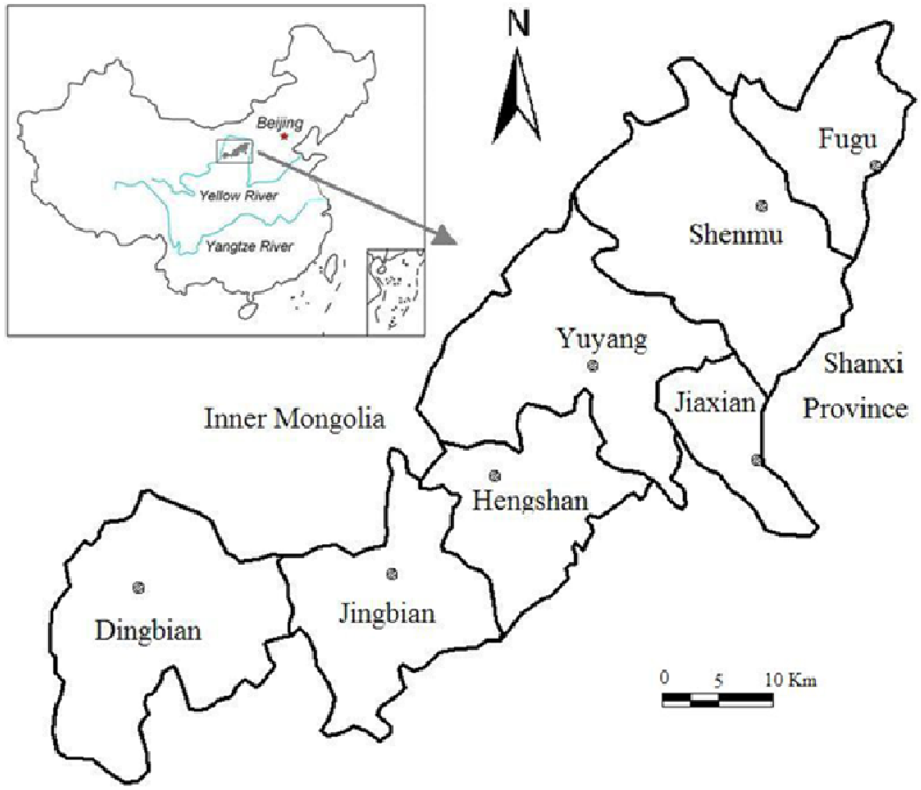

Figure 1. Location of the agro-pastoral transitional zone of northern Shaanxi Province.

semi-arid pastoral are the dominant land use types in the north-east (Yuyang, Jia County, Shenmu, Fugu). The main soil types are loess and sand.

Data pre-processing

Remote sensing images used in this study are from the Landsat 5 thematic mapper (TM), acquired in 1986, 1993, and 2003 and integrated into GIS. In order to undertake comparative analysis, the images were co-registered. Geometric correction was carried out using ground control points from topographic maps with a scale of 1:5000 produced in 1983 to geo-code the image from 2003. This image was used based on the quadratic polynomial method (Liu et al., 2008) to register the images from 1986 and 1993. Meticulous, per-pixel assessment showed that root mean-square errors among the three dates were less than 1 pixel, which is sufficient for multi-temporal comparisons.

In order to remove or normalize the reflectance variation between images acquired at different times, relative radiometric correction was performed to yield normalized radiometric data on a common scale (Paolini, 2006). After geometric correction, the images were enhanced by mosaic color composition and conversion, cross-tension, and histogram equalization based on ERDAS 8.5 image processing systems. Different bands were superimposed into false-color images for different scenes in the same path, which were set together, and path-to-path histogram normalization was performed (Liu et al., 2008).

The K-T transformation method was used for the spectral transformation (Liu et al., 2008) to reduce multi-spectral data volume with minimal information loss and generate a new image which loads main information from the original data, which is an effective technique to improve classification accuracy and change detection (Seto, 2002; Liu et al., 2008). A new image was obtained with using synthesis of image band colors (TM4 (R), 3 (G), and 2 (B)), which was used to directly identify specific physical attributes and can be easily interpreted for desert classification.

Data generation

A human-computer interactive approach was applied for sample selection, area identification, and template and discriminate function establishment. Vegetative cover is often an accurate representation of desertification (Zhu and Chen, 1994; Liu et al., 2008) and supervised classification was conducted based on the maximum likelihood classification method (Paolini, 2006). The initial distribution map of deserts in different periods of time was generated. After small patches were removed and non-type error pixels were marked, a vector desert grade map was obtained (Figure 2). Totally, three desert grades were identified in the map (mild, moderate, and severe) according to vegetative cover, species composition, and structure of plant communities (Table 1).

Using ArcGIS software, a spatial database was established after the vector classification map was edited and processed, and topological relations were created. Temporal and spatial evolution information was extracted and thematic maps were generated through spatial analysis and overlay of the vector classification maps.

Desert landscape characteristic variation model

Landscape fragmentation analysis is frequently used to interpret the impact of land cover changes within a landscape, by calculating, for each land cover class, a range of metrics to describe fragmentation

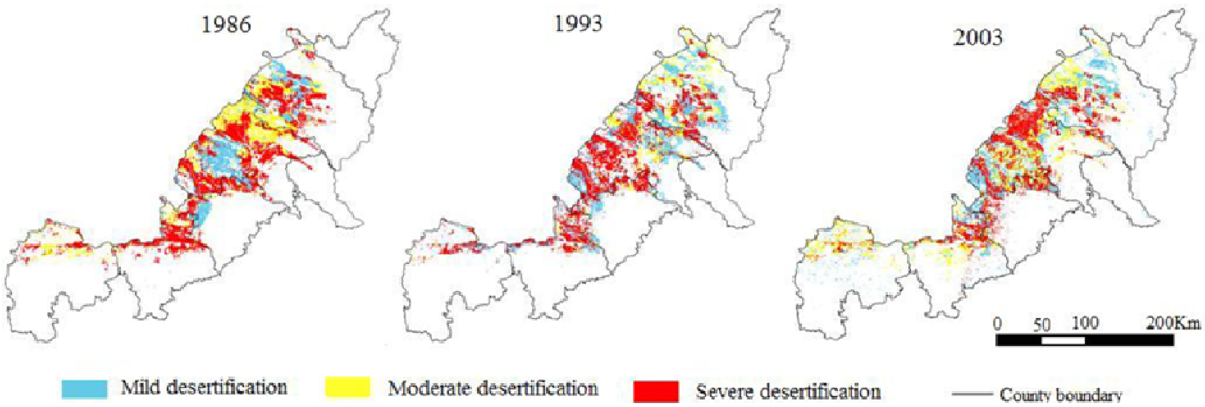

Figure 2. Spatial distribution of desertification in 1986, 1993, and 2003 of the agro-pastoral transitional zone of northern Shaanxi Province.

Table 1. Grading system of desertification land in an agro-pastoral transitional zone of northern Shaanxi Province.

Desertification grade	Description
Mild	Sand area is more than 10% of the patch area, vegetation is predominantly shrubs, vegetation coverage is more than 50%, and fixed dunes are the dominant landscape feature.
Moderate	Sand area is 10 to 50% of the patch area, vegetation is moderate with slight shrub predominance, vegetation coverage is 10 to 50%, semi-fixed dunes or several fixed dune dispersions are the dominant landscape features.
Severe	Sand area is less than 50% of the patch area, vegetation is sparse with little shrub presence, vegetation coverage is less than 10%, moving dunes or several semi-fixed dune dispersions are the dominant landscapes.

and spatial distribution, often using satellite-based land cover classifications (Southworth et al., 2004). Analyzing changes in spatial patterns over time facilitate the identification of social and biophysical processes that drive these changes (Brown et al., 2000). The landscape fragmentation index (LFI) is frequently used to indicate landscape fragmentation degree. The LFI formula is as follows:

$LFI_i = Ni/Ai$ (Equation 1)

Where LFI_i is the landscape fragmentation index of the *i* land type, *Ni* and *Ai* are the patch number and the total area of the *i* land type, respectively. Here, the LFI is between 0 and 1, higher LFI indicates a higher landscape fragmentation degree. Landscape variation in space can also be identified by a change in the spatial center. This type of analysis was introduced from geographical field of population distribution and the formula has been described by Wang and Bao (1999):

$$X_t = \sum_{i=1}^{m}(C_{ti} \times X_i) \Big/ \sum_{i=1}^{m} C_{ti} \quad (2)$$

$$Y_t = \sum_{i=1}^{m}(C_{ti} \times Y_i) \Big/ \sum_{i=1}^{m} C_{ti} \quad (3)$$

Where *Xt*, and *Yt*, are the latitude and longitude centers of the landscape in year *t*, respectively; *Cti* is the patch area of landscape *i* in year *t*, *m* is the landscape type; and *Xi* and *Yi* are the latitude and longitude centers of the landscape *i*, respectively.

Correlation analysis

Natural and society-economic data, such as percipition, temperature, population, cultivated land area, livestock population, gross industrial output value, which are related to desertification dynamics were obtained from statistical year books of Yulin City. To identify the effect of the possible affecting factors, correlation analysis between desert area variation and natural and anthropogenic variation was conducted using SPSS software.

RESULTS

Spatio-temporal variation of desert land

Generally, desert severity has decreased over the past 17 years, even though the extent of desertification has increased in the area by 5.1%. Severe desert land area has decreased by 26.8% from 1986 to 2003, and is no longer the most dominant grade. Distribution of the moderate desertification grade is in the shape of "v", and the area decreased from 1986 to 1993 and increased again from 1993 to 2003. The extent of moderate desert

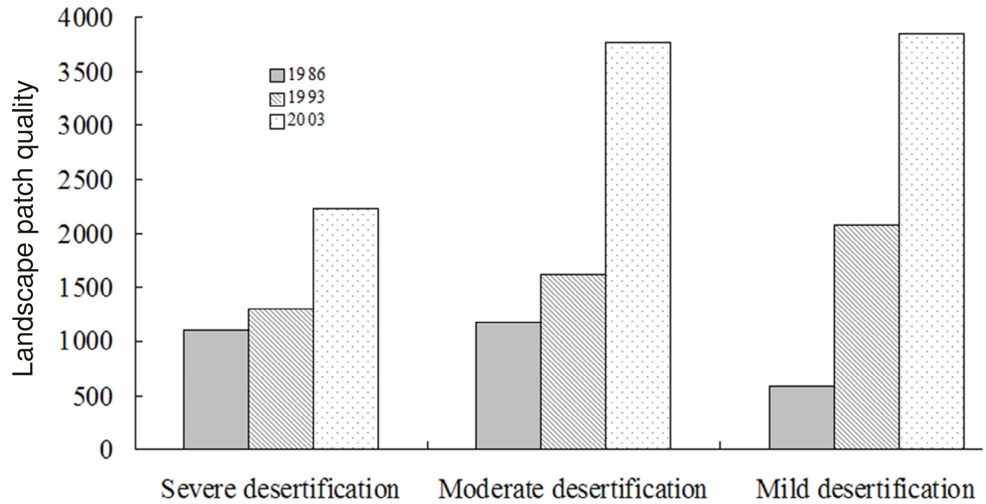

Figure 3. Changes in desert landscape patche quantities 1986, 1993, and 2003 in the agro-pastoral transitional zone of northern Shaanxi Province.

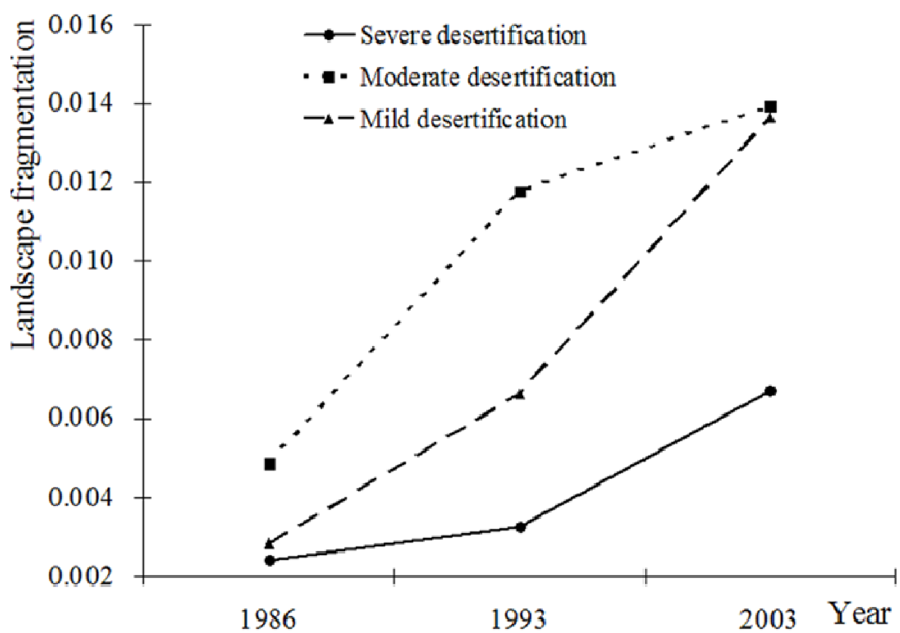

Figure 4. Changes in desert landscape fragmentation from 1986 to 2003 in the agro-pastoral transitional zone of northern Shaanxi Province.

land area has increased significantly from 1986 to 2003 and became the most dominant desert grade in 2003. Inverse to the moderate desert land distribution, the distribution of mild desert is in the shape of "∧", and the land area increased from 1986 to 1993 and then decreased from 1993 to 2003.

Quantities of desert patches have increased significantly from 1986 to 2003 (Figure 3). For mild desert, quantity of patches increased by 549% from 1986 to 2003. The average area of the patches decreased by 63.9, 65, and 79.2% for severe, moderate, and mild desert grades, respectively, which indicates that landscape fragmentation extent has increased significantly. This is also evidenced by lower landscape fragmentation. From 1986 to 2003, the desert landscape fragmentation index has increased gradually, which indicates an intense cutting degree of the landscape, obvious fragmentation, and an overall reduction in desertification (Figure 4). Over the past 17 years, the desert areas have mainly been distributed north of the Great Wall, which includes north

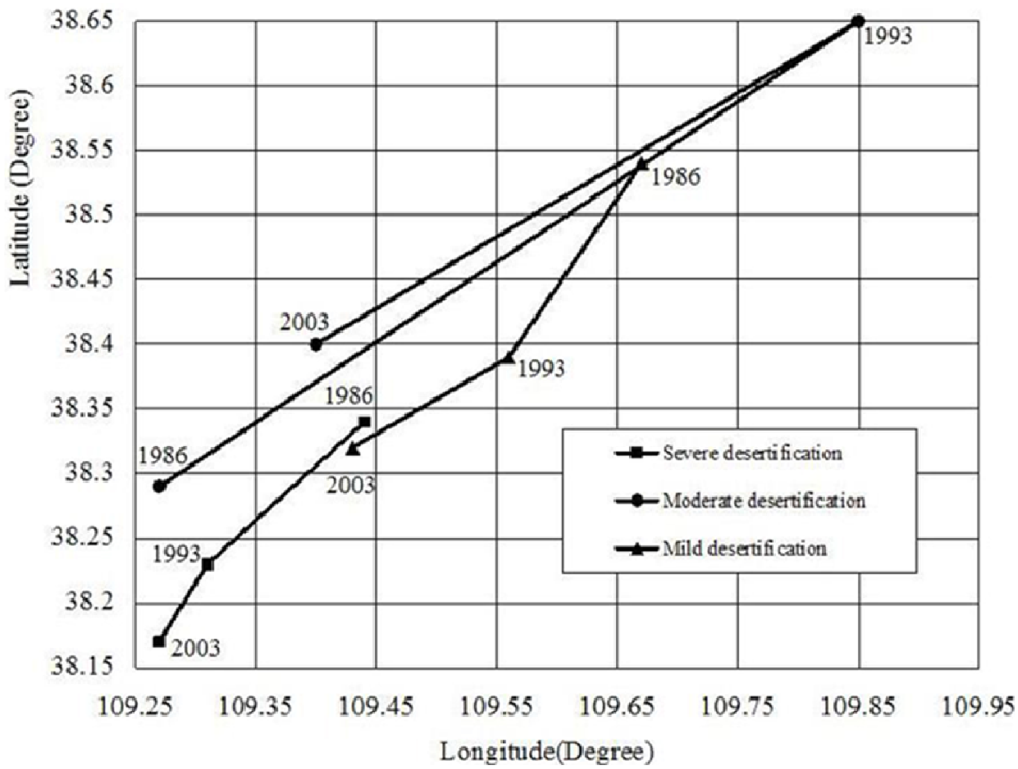

Figure 5. Changes in spatial center of desert landscape patches in 1986, 1993, and 2003.

Dingbian and Jingbian Counties, north-west Hengshan and Shenmu Counties, the majority of Yuyang County, and fragmentary distribution in Fugu and Jia Counties. In those areas, the significant characteristic is widespread wind-drift sand, meniscus dunes, and chaining dunes (Figure 2). From 1986 to 1993 the severe desert areas decreased the moderate desert areas shifted to the north, and the mild desert areas are fragmentarily distributed in Dingbian and Jingbian Counties. Large areas of mild desertification have become severe in north of the reservoir in Yuyang County.

Moderate desertification decreased and surface vegetation cover increased in the Wudao river valley and in north-west Shenmu County, however, severe desertification significantly increased in the town of Daliuta. Hengshan, Dingbian, and Shenmu Counties have the most active desertification areas, where desert land has expanded and is threatening the natural ecology of the Loess plateau in the southeast. From 1993 to 2003, large areas of moderate desertification increased in the Dingbian-Jingbian belt, and expanded to the south by 1993. Severe desertification shifted to the east and large areas of mild desertification, covered by drift dunes, increased in Hengshan County.

From 1986 to 2003, the center of the desert landscape migrated from 0.18° to the west and south for the severe desert and the desert land has expanded to the south-west for 24,293 m totally (Figure 5). From 1986 to 1993, the center of the landscape migrated from 0.44° to the east and 0.34° to the north for moderate desert, and the desert land has expanded to the north-east for 64019 m totally. From 1993 to 2003, moderate desert has expanded to the south-west for 53,559 m. From 1986 to 2003, the center of the landscape migrated from 0.13° to the east and 0.11° to the north for moderate desert, and 11,693 m migrated to the north-east. During the same time period, the center of the landscape migrated from 0.24° to the west and 0.22° to the south for mild desert and 32,891 m migrated to the north-west.

Transformation of land types

Since 1986, increased desert extent has mainly affected farm land and forest land, which accounted for 55.3 and 25.7% of all land area transformation, but the grassland have not been significantly affected (Table 2). From 1993 to 2003, more than 110,000 ha forest has been transformed into desert, which accounts for 37% of desert land area increase (Table 2). During this period massive amount of desert land has been transformed into other land types through comprehensive reclamation. From 1986 to 1993, desert land was controlled by forestation and development of farm land, while from 1993 to 2003, desert land was reclaimed through vegetative restoration and farming. During the research period, more than

Table 2. Transformation matrix of land use type in an agro-pastoral transitional zone of northern Shaanxi Province.

Land use type	Land converted to desert		Desert converted to other land use types	
	1983 to 1996	1996 to 2003	1983 to 1996	1996 to 2003
Arable	20.256	13.125	8.992	14.350
Forest	4.337	11.177	12.398	2.549
Grassland	2.304	1.760	2.777	2.170
Civil and Industrial	0.010	0.007	0.039	0.057
Unusable	3.175	4.151	4.590	7.727
Total	30.082	30.220	28.791	26.853

Table 3. Transformation matrix of desert type in an agro-pastoral transitional zone of northern Shaanxi Province.

Desert grade	1986 to 1993				1993 to 2003			
	Severe	Moderate	Mild	Total	Severe	Moderate	Mild	Total
Severe	20.449	7.079	7.768	35.296	19.667	9.169	6.242	35.078
Moderate	4.840	4.526	6.467	15.833	2.402	11.014	2.242	15.659
Mild	6.741	1.534	2.776	11.050	3.683	3.424	7.529	14.636
Total	32.030	13.139	17.011	63.179	25.754	23.607	16.013	65.373

Table 4. Coefficients of variation of desert extent and affecting factors in northern Shaanxi, China.

	Annual precipitation	Annual temperature	Population	Cultivated land area	Livestock number	Gross industrial output value
Desert extent	-0.908**	0.987**	0.985**	0.981**	0.776*	0.964**

**Denotes significance at $p < 0.01$; * denotes significance at $p < 0.05$.

300,000 ha of severe desert was transformed into moderate and mild desert, and about 87,000 ha moderate desert was transformed into mild desert (Table 3).

Meanwhile, more than 170,000 ha moderate and mild desert was transformed into severe desert, and about 5,000,000 ha mild desert was transformed into moderate desert, particularly from 1986 to 1993. Also, about 67,000 ha mild desert was transformed into severe desert.

Correlation between desertification and affecting factors

Significant correlations were found between desert extent and both natural and anthropogenic factors. For natural factors, annual precipitation and temperature had correlation coefficients of -0.908 and 0.987, respectively. For anthropogenic factors, correlation coefficients were 0.985, 0.981, 0.776, and 0.964 for population, cultivated land area, livestock populations, and gross industrial output value, respectively. All correlation coefficients were significant at $p < 0.01$ except gross industrial output value, which was significant at $p < 0.05$ (Table 4).

DISCUSSION

Spatial variation of desertification

It was recorded in the Tang Dynasty (1400 years ago) that the region near the Great Wall was a beautiful area with vast pasture and clear streams (Department of Geography of Peking University, 1983). Since then, it has gradually become a mosaic of shifting, semi-fixed, and fixed deserts, due to its semi-arid climate. This has been exacerbated by war between the Han and minority nationalities living in northern China (Wu and Ci, 2002), who, following turbulent times would send troops and immigrant farmers to reclaim grasslands. From 1986 to2003, desert areas have expanded to the south-west and north-east. Meanwhile, the desert severity has decreased during the same period. Much severe desert land area has been converted into moderate and mild grades, and the proportion of the later has increased from 50% in 1986 to 65% in 2003.

This study indicates that desertification is being controlled, to some degree, through large-scale ecological and environmental government programs. Many desert

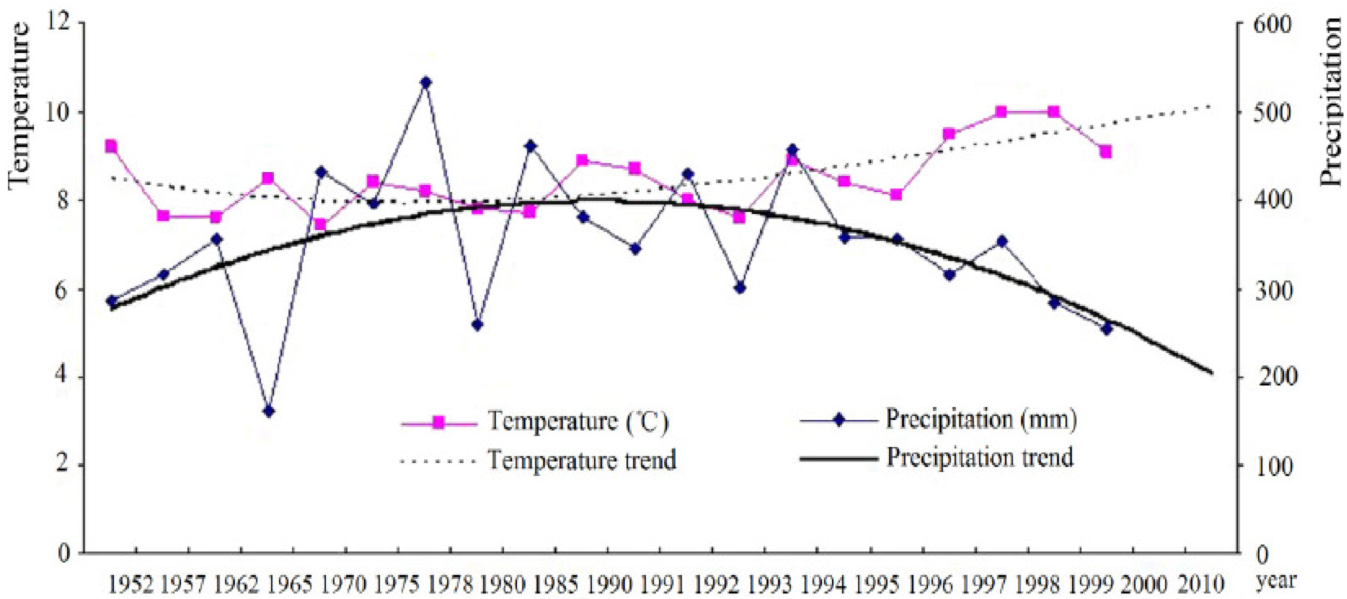

Figure 6. Annual temperature and precipitation trends from 1952 to 2002 in the agro-pastoral transitional one of northern Shaanxi Province.

areas have been covered with higher vegetation coverage. However, in this fragile area, land surface and vegetation cover is unstable, precipitation is decreasing, and forests and grasslands suffering from lack of water. This, combined with irrational human activity leaves the ecology of the study area unstable.

Climate change and desertification

Desertification is a complicated process due to the variety of natural conditions and human activities involved. In earlier eras, climate change was considered to be the dominant cause for desertification. Especially during the 1970's, middle-term climate changes and short-term droughts were considered to be the major causes of desertification in Europe (Wu and Ci, 2002). Desertification can, however, be exacerbated or triggered by climate variability (Pickup, 1998), even though it is difficult to quantify the relative contributions of climate change and human activities. Among the climate factors, precipitation, temperature, evaporation, and wind are the most important contributors to desertification. The agro-pastoral transitional area is located at the transition zone of the Ordos plateau and the Loess plateau, as well as at the junction of the arid and semi-arid climate regions.

In the winter and spring, due to powerful cold air masses moving south-east from Siberia, strong winds develop easily and the average wind speed is 16.5 m s^{-1}. Wind-drift sand and mobile dunes are abundant due to the scarcity of wilderness prairie vegetation. In the spring, inadequate rainfall, dry land surface, as well as frequent strong winds, with an average of 9.3 strong wind days from March to May, intensify wind erosion and sand storms. During this season, seeds have still not begun to germinate, causing surface vegetation coverage to be sparse. These factors may be responsible for the migration of the desert to the south-east. Temperature increased during the 1980's after a gradual reduction from 1950 to 1985. Inversely, precipitation significantly decreased after a gradual increase from 1950 to 1985 (Figure 6).

Predictions call for the climate to become increasingly warmer and drier over the next several decades. The trend from the 1950's to 2003 and even into the near future favors increased desertification in the area.

Human activity and desertification

Since the 1970's, more researchers have recognized the role of human activities on desertification, and the impact of land use practices on land degradation has been acknowledged (Wu and Ci, 2002). In the Canary-Islands of Spain, a wide-range of factors, both natural and anthropogenic, caused fragile ecosystems and agricultural land to become desert and progressive degradation of soil productivity (Rodriguez et al., 1993). A study in Karoo, South Africa shows that land use, not climate, has driven the decline of grasses in this area (Bond et al., 1994). In the Kalahari Desert of Botswana, boreholes and wells used for supplying water to livestock are considered central to the spread of desertification (Perkins and Thomas, 1993).

As investigated by the Lanzhou Institute of

Desertification of the Chinese Academy of Sciences in the 1980's, 94.5% of desert expansion was caused by the anthropogenic factors, and unreasonable land use by humans was the dominant contributor to desertification in northern China. Sun et al. (2006) reported that a number of agricultural activities are causing desertification in Minqin County, China. In the agro-pastoral transitional zone, human activities, including population increase, over-grazing, inadequate reclamation, and mining, are significant contributors to modern desertification. The population has significantly increased from 689,800 in 1951 to 2,129,900 in 2003. The population density is 58.9 per km^2, significantly over the standard proposed by the United Nations.

Increasing population induced the increasing need for basic resources, such as food, which caused exploitation of available resources. Subsequently, land intensive management induces desertification in fragile environments. Rich natural grasslands have encouraged livestock production, which plays an important role in economic development of the research area. Livestock populations increased from 673,000 in 1950 to 1,369,000 in 2003. Consequently, over-grazing has caused wide-spread grassland degradation. The soil surface has also been destroyed by the livestock induced compaction (Wu and Ci, 2002). To meet population demands, grasslands reclaimed for agriculture. Reclaimed grasslands were subsequently eroded or buried by shifting sands due to the shortage of protection measures. Therefore, after reclamation, grasslands were often quickly abandoned. At the same time, the abundant resources underground, such as coal, petroleum, and natural gas, have been explored since the 1990's, which has greatly contributed to local economic development, and subsequently induced urbanization.

Mining and urbanization often destroys surface vegetation, soil structure, and water resources (Wu and Ci, 2002).

Projects to combat desertification

Desertification processes reflect a feedback mechanism between human activities and the environment. Fortunately, local officials have recognized the harm of desertification and paid more attention to controlling desertification. Planting shrubs to elevate vegetation coverage is the main approach used for desertification control. Two projections have been applied to the agro-pastoral region of northern Shaanxi province to control desertification: The "three north shelterbelt program" and the "grain-for-green project".

Since the 1950's, the "Three North Shelterbelt Program", aimed at fixing the shifting sands and preventing the expansion of desertification, has been applied by the government of Yulin City. The city re-forested many areas and also used aerial seeding in other areas. The re-forested area of Yulin increased from the late 1950's to the early l960's, but decreased in the 1960's and early 1970's. Since the 1980's, due to increased investment, the forestation has increased steadily (Wu and Ci, 2002). Statistically, since the 1980's, 93,750 ha desert land has been controlled, in which 10,000 ha desert has become farmland and 940,00 ha has been converted into forest, and 40,000 hm has been converted into artificial grass. The vegetation cover increased from 24.5% in 1986 to 74.3% in 2003. This is largely responsible for the reduction in desert severity from 1986 to 2003. Since 1998, a nation-wide ecological restoration project, named the "grain-for-green project", was launched and regulations were enacted by the central government, which have played an important role in controlling desertification in China (Oñate and Peco, 2005; Liu et al., 2008).

This project aims to reduce cropland which is not suitable for cultivation to restore natural vegetation (Liu et al., 2008). In the research area, a series of measures aimed at lessening disturbance and increasing the coverage of natural vegetation, were enacted by local governments to control further ecological degradation. These measures included grazing prohibition, plantation of high yield forage grasses, aerial seeding, and adjustment of the socio-economic structure. After several years' practice, desertification greatly decreased. From this research, we believe these measures were effective in controlling land degradation. However, because restoration of the damaged ecosystems is a slow process, the policies also need a long time to be validated.

Conclusions

In general, desertification in the agro-pastoral transitional zone in northern Shaanxi, China is decreasing in severity, but expanding to the south-east and threatening the Loess plateau. Even though the relative contributions of climate change and human activities on desertification cannot be conclusively quantified, these two factors are both responsible for desertification reversal and expansion. The projects carried out by the local and national governments were the dominant contributors to the desertification reversal. Therefore, we conclude that desertification control is a difficult and gradual process, and the government should play a leading role in this process.

ACKNOWLEDGEMENTS

The authors are grateful for funding from the National Foundation of China (No. 30872073).

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