J. Geogr. Sci. 2011, 21(5): 926-936
DOI: 10.1007/s11442-011-0890-1

© 2011 Science Press Springer-Verlag

Assessment of the relative role of climate change and human activities in desertification: A review

XU Duanyang[1,4], LI Chunlei[2], ZHUANG Dafang[3], PAN Jianjun[4]

1. Institute of Scientific and Technical Information of China, Beijing 100038, China;
2. Xinjiang Normal University, Urumqi 830054, China;
3. Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China;
4. Nanjing Agricultural University, Nanjing 210095, China

Abstract: Climate change and human activities are the two kinds of driving forces in desertification, and assessing their relative role in desertification is of great significance to deeply understanding the driving mechanisms and preventing desertification expansion. This paper has systematically reviewed the progress of the researches on assessing the relative role of climate change and human activities in desertification from qualitative, semi-quantitative and quantitative aspects respectively. The authors found that there were still some problems in the previous researches. For example, the subjectivity in assessment was obvious, the assessment cannot be easily repeated, and the assessment and its results were always based on administrative regions and less taken and expressed in a continuous space. According to the progress of previous researches and the works conducted by the authors recently, we put forward a quantitative approach by selecting NPP as a common indicator to measure the relative role of climate change and human activities in desertification and dividing the ecological process of "driving force effect-dynamic response of desertified land" into several scenarios. Meanwhile, validation and scale of assessment should be taken into account when quantitative assessment of the relative role of climate change and human activities in desertification are carried out.

Keywords: desertification; climate change; human activities; relative role; assessment

1 Introduction

Desertification is one of the most severe global social-economic-environmental issues of our time, which threatens human survival and development (Wang and Zhu, 2003). China is one of the countries that seriously suffered from desertification in the world. According to the statistics of State Forestry Administration in 2004, the desertified area in China reached 1,739,700 km^2, which accounted for 18.12% of the country's total land area (State Forestry

Received: 2010-11-23 **Accepted:** 2010-12-29
Foundation: National Natural Science Foundation of China, No.40901054
Author: Xu Duanyang (1983–), Ph.D, specialized in climate change, desertification and scientific policies.
E-mail: xudy@istic.ac.cn

Administration, 2007). The problems induced by desertification, such as soil quality decline, land resources reduction, and sand storm etc., had seriously restricted the sustainable development of economy and society in China. In recent years, with more and more effective policies and projects implemented by the Chinese government to combat desertification, the total area of desertified land in China was less than that in the late 1990s, and some typical desertified areas such as Horqin Sandy Land and the southern Mu Us Sandy Land experienced an obvious desertification reversion; however, the general status of desertification in China is still serious (State Forestry Administration, 2007; Wang, 2004).

Deeply understanding the driving mechanisms of desertification and assessing the relative role of different driving factors are the fundamental and key points to combat desertification. Although climate change and human activities as two kinds of driving forces in desertification have been generally accepted, people have always paid much attention to getting to know the relative role of climate change and human activities in desertification (Wang, 2003). However, due to the interactions among many driving factors in the desertification process, the driving mechanisms of desertification is so complex that it is very difficult to assess the relative role of climate change and human activities in desertification under an independent condition, which becomes a bottleneck in the research of desertification. In recent years, many researches were conducted to assess the relative role of climate change and human activities in desertification and gained a great progress (Zhang, 2000; Wang *et al*., 2004; Gao *et al*., 2005; Ma *et al*., 2007; Li *et al*., 2007; Wessels *et al*., 2008; Xu *et al*., 2009; Wang *et al*., 2010); however, there still existed some problems in these previous researches. In this study, the authors systematically reviewed the progress and problems in the researches on assessing the relative role of climate change and human activities in desertification, and then put forward a quantitative assessing approach based on absorbing the advantages in previous researches and combining the recent works conducted by authors, which aimed to support the research of driving mechanisms of desertification and its combating.

2 Progress in the researches on assessing the relative role of climate change and human activities in desertification

2.1 The qualitative and semi-quantitative assessment

According to the previous researches, the methods used to assess the relative role of climate change and human activities in desertification can be divided into two types: one is qualitative and semi-quantitative assessment and the other is quantitative assessment. Qualitative and semi-quantitative assessment of the relative role of climate change and human activities in desertification was commonly conducted by using the expertise based on the combination of the dynamics of desertification with the information of the changing trends of climate and human factors or with some indicators that can reflect the effects of climate change and human activities in a specific period. There are many researches that used qualitative and semi-quantitative method to assess the relative role of climate change and human activities in desertification in recent 50 years in typical regions of China (Wang *et al*., 2004; Gao *et al*., 2005; Ma *et al*., 2007; Liu and Wang, 2004). Wang *et al*. qualitatively assessed the relative role of climate change and human activities in desertification in the Horqin Sandy Land by analyzing the changing trends of climate and human factors during the last 40 years, and drew a conclusion that human activity was the dominant factor in desertification, which reflected that the type change and extensive use of land accelerated the desertification process (Wang *et al*., 2004). Gao *et al*. used qualitative and semi-quantitative method to analyze the dynamics and driving mechanisms of desertification in the zone along the Great Wall in northern Shaanxi province during 1986–2000, and concluded that the implementation of measures in combating desertification and government policies were the main factors that induced the desertification reversion in this period (Gao *et al*., 2005). Meanwhile, what-if scenario analysis was always brought into the qualitative and semi-quantitative assessment to support the expert decision, such as Zheng *et al*. conducted a research to assess the relative role of climate change and human activities in desertification of Otindag in the past 40 years, when only the climate change was considered, the changing trends of Net Primary Production (NPP, NPP=0.0119Year–22.672) and Foliage Projective Cover (FPC, FPC=0.1109Year–171.84) showed that the climate change would be beneficial to vegetation growth, so the researchers concluded that climate change was not the dominant factor induced desertification expansion in this region (Zheng *et al*., 2006). The qualitative and semi-quantitative method was also frequently used to assess the relative role of climate change and human activities at large scale, such as based on the trends analysis of precipitation, evaporation, temperature, sand-driving wind, drift potential, population, livestock number and afforested area in northern China from 1950 to 2000, Wang *et al*. analyzed the relationship between desertification dynamics and the changing trends of driving factors, and then indicated that the relative role of human activities (including the Three Norths Forest Shelterbelt Program) in desertification reversion might be overestimated (Wang *et al*., 2006, 2010).

2.2 The quantitative assessment

In recent years, with the comprehensive applications of mathematic model and approach in geography and ecology, more and more researches began to use quantitative methods to assess the relative role of climate change and human activities in desertification (Table 1). According to the previous researches, these quantitative methods can be divided into four types: the first is the method based on using regression model; the second is the method based on using principal component analysis model; the third is the method based on comparing potential (without human disturbance) and actual condition; the fourth is the method based on selecting a common indicator to measure the impacts of climate change and human activities on desertification.

2.2.1 The method based on using regression model

This method selected regression model as the analyzing tool to build the relationship of the dynamics of desertification and its driving factors, and then assess the relative role of them (Xu and Yan, 2005; Sun, 2005; Zhang *et al*., 2003). Xu and Yan used linear regression model to analyze the effect of human activities such as magnitude of population growth, cultivation index, output value of annual mean forestry product and annual mean afforested area on desertification in northern Shaanxi province. The results showed that only cultivation index has a negative correlation with the desertification index, while the other factors showed a positive correlation with the desertification index (Xu and Yan, 2005). Sun used a stepwise multi-variables regression model to analyze the effect of socio-economic driving forces on

Table 1 Quantitative methods for assessing the relative role of climate change and human activity in desertification

Assessment method	Research region	Key indicator	Model/result	Reference
Ⅰ	North of Shannxi province, China	Population growth (X1), cultivation index (X2), output value of annual mean forestry product (X3), annual mean afforested area (X4), desertification index (Y)	Y=1.0437X1-0.2836 Y=-0.036X2+0.6687 Y=0.0008X3-0.2555 Y=0.0275X4-0.2619	Xu *et al*., 2005
	Minqin, Gansu province, China	Yearly changing rate of crop sown area (AGr), sheet number per hectare (ASh) and other 8 socio-economic indicators	Pasture region: Rate=0.14+22.9Ash dam irrigated region: Rate=1.01+1.37AGr	Sun, 2005
	Shule River, China	Rainfall, wind speed, gale days, population, agricultural acreage	Coefficient of correlation analysis $R_{\text{wind speed}}$=0.45 $R_{\text{population}}$ =0.84 $R_{\text{agricultural acreage}}$ =0.58	Zhang *et al*., 2003
Ⅱ	Gonghe basin, China	Rainfall, gale days, agriculture population, livestock number, agricultural acreage	Contribution rate of human activities was 46.5%; contribution rate of natural factors was 24.6%	Zhang, 2000
	Minqin, Gansu province, China	Rural population, agricultural acreage, livestock number, gale days, rainfall, temperature etc.	Contribution rate of human activities in 1956-2004 was 56.33%, and it in 1981-2004 reached 66.19%	Ma *et al*., 2007
	West Hainan island	Temperature, rainfall, wind speed, livestock number, agricultural acreage, population, afforested area etc.	Contribution rate of human activities was 41%; contribution rate of climate change was 23.7%	Li *et al*., 2007
Ⅲ	Naiman Banner, China	Area of drift sand (x), vegetation cover (y)	$y = 83.57e^{-0.0378x}$ Contribution rate of natural factors in 1987-1991 was 63.59%	Li *et al*., 2006
	South Africa	NDVI, NPP, rainfall	—	Wessels *et al*., 2007, 2008
	Sahel	NDVI, rainfall	—	Herrmann *et al*., 2005
Ⅳ	Guinan steppe, China	Wind speed (U), vegetation cover (VC), livestock trampling (TR), woodcutting (DR), soil roughness (Z0), wind erosion rate (Q)	$Q = \exp(-4.97334 + 1.3211TR)$ Contribution rates of TR, DR and grassland cultivation were 54.78%, 4.66% and 40.56% respectively	Zhang *et al*., 2005
	Globe	NPP	LPJ-GDVM	Zika *et al*., 2007

Note Ⅰ: the method based on using regression model; Ⅱ: the method based on using principal component analysis model; Ⅲ: the method based on comparing potential and actual condition; Ⅳ: the method based on selecting a common indicator.

land desertification in Minqin county during 1988–1997 by selecting the yearly changing rate of desertification as dependent variable (Rate), and the yearly changing rate of crop sown area (AGr), and of sheet number per hectare (ASh) as independent variables, based on which the researchers developed different models to identify the key driving factors in desertification for different regions (such as the model for pastoral area was Rate=0.14+ 22.9Ash; the model for dam irrigated area was Rate=1.01+1.37AGr) (Sun, 2005).

2.2.2 The method based on using principal component analysis model

The second quantitative assessment method is that using principal component analysis (PCA) or factor analysis (FA) model to assess the contribution of different driving factors to desertification. The PCA or FA as a statistical multivariate method resulting in data reduction can compress the variables into some uncorrelated components, which can express the major information of variables. The percentage of total variance explained by variables was always treated as the contribution rate of driving forces to desertification when using this method to assess the relative role of climate change and human activities in desertification (Dong, 1989;

Zhang, 2000; Ma *et al*., 2007; Li *et al*., 2007). Since Dong used PCA model to analyze the driving mechanisms of desertification for the first time (Dong, 1989), many researches have been conducted by using this method to assess the relative role of climate change and human activities in desertification (Zhang, 2000; Ma *et al*., 2007; Li *et al*., 2007). For example, Zhang assessed the relative role of climate change and human activities in desertification of Qinghai Gonghe Basin by using PCA, and indicated that the contribution rates of climate change and human activities to desertification were 24.6% and 46.5% respectively, and the joint contribution of them to desertification reached 14.9% (Zhang, 2000). As for the research conducted by Ma *et al*. to analyze the effect of driving forces on desertification in Minqin county, the results of PCA showed that human activities were the dominant factor in desertification during the period from 1956 to 2004 and the contribution rate of human activities to desertification was 56.33%; this feature was more obvious from 1981 to 2004, and the contribution rate of human activities reached 66.19% in this period (Ma *et al*., 2007).

2.2.3 The method based on comparing potential and actual condition

The method based on comparing potential and actual condition was to analyze the difference between the desertification developed under the condition without human disturbance and the actual status, and then estimate the effect of climate change indirectly. Li *et al*. had used this approach to assess the relative role of climate change and human activities in desertification in Naiman Banner, China. In their research, sand transport rate and biomass were selected as indicators to develop the desertification predicted model, and the method to assess the contribution rate of natural factors to desertification was built by comparing the difference between the outputs from the predicted model to the monitoring data. Meanwhile, the contribution rate of human activities to desertification can also be estimated indirectly. According to the results, climate change was the dominant factor in desertification in Naiman Banner during the period from 1987 to 1991, and its contribution rate to desertification reached 63.59% (Li *et al*., 2006). However, some researches conducted in other countries always focused on the vegetation change induced by land degradation or desertification. From this aspect, the effects of climate change and human activities on land degradation or desertification could be distinguished indirectly. Evans and Geerken developed a vegetation production predicted model by using the good relationship between the accumulated precipitation and Normalized Difference Vegetation Index (NDVI), the vegetation production predicted by this model can be considered as the results of climate change, and the differences (also called residuals) between the observed and predicted production can be attributed to human activities (Evans and Geerken, 2004). Based on this approach, some related researches had been conducted to assess the relative role of climate change and human activities in desertification in South Africa, Syria and African Sahel (Wessels *et al*., 2007; Geerken and Ilaiwi, 2004; Herrmann *et al*., 2005; Archer Emma, 2004; Wessels *et al*., 2008). For example, based on comparing the vegetation production predicted from rainfall to the actual conditions in the period from 1982 to 2003, Herrmann *et al*. pointed out that the increasing of rainfall was the principal cause for the vegetation recovery in this period; however, human activities had also played some positive role in desertification reversion and vegetation recovery (Herrmann *et al*., 2005).

2.2.4 The method based on selecting a common indicator

The fourth quantitative assessment method is that using a common indicator to measure the impacts of different driving factors on desertification, and then assessing the relative role of climate change and human activities. For example, Zhang *et al.* selected wind erosion rate as the common indicator to measure the impact of the changes of wind speed, vegetation cover, livestock trampling, woodcutting and grassland cultivation on desertification status and its development by using wind tunnel test and ^{137}Cs technique when assessing the contribution of driving factors to the steppe desertification in Guinan, Qinghai Province, China. The results of Zhang's research showed that the contribution rates of livestock trampling, woodcutting and grassland cultivation to desertification were 54.78%, 4.66% and 40.56%, respectively, which indicated that human activities were the dominant factor of the desertification expansion in recent 40 years (Zhang *et al.*, 2005). Meanwhile, NPP was always selected as the common indicator to assess the impacts of climate change and human activities on ecosystem. Especially in recent years, some researchers used HANPP (Human Appropriation of Net Primary Production) as an indicator to measure the impact of human activities on regional and global ecosystems (Rojstaczer *et al.*, 2001; Haberl *et al.*, 2002; Haberl *et al.*, 2007; O'Neill *et al.*, 2007), and this method was also used to assess the role of human activities in desertification. For example, Zika *et al.* selected HANPP as the indicator to measure the loss of NPP induced by human-made desertification, based on which the impact of human activities in desertification could be assessed (Zika and Erb, 2007).

3 Analysis of the problems of these existed methods

3.1 Analysis of the problems of qualitative and semi-quantitative assessment methods

With the researches of desertification driving mechanism conducted more and more deeply, the methods that to assess the relative role of climate change and human activities in desertification became more and more varied and mature. However, there were still some problems in these methods mentioned above. For the qualitative and semi-quantitative assessment method, although it was used based on analysis of the changing trends of driving factors and also combined with the expertise, the obvious subjectivity might make different researchers draw different conclusions when assessing the relative role of climate change and human activities in desertification in the same region. Meanwhile, when the qualitative and semi-quantitative assessment was taken at a large scale, such as assessing northern China, it would be time-consuming and the results of assessments for different sub-regions would not be compared.

3.2 Analysis of the problems of the quantitative assessment method

Due to the problems in the qualitative and semi-quantitative assessment method, more and more researchers try to use quantitative method to assess the relative role of climate change and human activities in desertification. However, based on analysis of the quantitative assessment method, we found that there were still some problems. For the method based on using regression model, the relationship between desertification process and driving forces was assumed as linear; however, as a part of land surface ecosystem, the characteristics of desertified land ecosystem such as openness, dissipative structure and the nonlinearity between the driving factors and response to the outside world could not make the linear regression model completely simulate the relationship between the driving factors and process of desertification. Meanwhile, the desertification of the entire research region was always selected as the dependent variable in the assessment by using this method, which would make it difficult to measure the differences of desertification driving mechanism among the sub-regions. For the method based on using PCA model, the data of driving factors was only used to run the model; however, the desertification data was not taken as an essential parameter in model simulation. In addition, the method always took the administrative district as research region, and the data of driving factors used in this method were region-averaged, which did not consider the spatial heterogeneity in the research region at grid scale. Besides, different conclusions would be drawn by different researches due to the subjectivity in the process of model results explanation.

Although the last two quantitative assessment methods provided novel approaches to assess the relative role of climate change and human activities in desertification, both of them needed to be improved further. The third quantitative assessment method, such as that provided by Li *et al*. can calculate the contribution of climate change and human activities to desertification based on distinguishing the effect of climate change from human activities; however, it also ignored the spatial heterogeneity in the research region, and cannot express the assessing results in a continuous space, which was the same problem existed in the first and the second quantitative assessment methods. According to the research conducted by Wang in China, the key to assess the relative role of driving factors in desertification is to select an indicator that can reflect the effects of both climate change and human activities on desertification, and use this indicator to measure and compare these effects (Wang, 2003). The fourth quantitative assessment method was based on this theory, such as the research conducted by Zhang *et al*. However, the key technologies used in Zhang's research such as wind tunnel test and ^{137}Cs technique cannot be applied at large scale, and the simulation was not easily repeated. Meanwhile, the data of driving factors used in Zhang's research were also region-averaged, so the results can only reflect the relative role of driving factors at regional level, which also ignored the spatial heterogeneity in the research region. According to these analyses, how to quantitatively assess and express the relative role of climate change and human activities in desertification in a continuous space of a specific region became an important choke point in developing the method of assessment.

4 The approach of assessing the relative role of climate change and human activities in desertification

4.1 The basic approach of assessment

According to the review of these previous researches on assessing the relative role of climate change and human activities in desertification, we thought that the assessment method should be quantitative, and it could be developed based on dividing the basic model of the ecological process of "driving force effect-dynamic response of desertified land" and combining the advantages of the third and fourth quantitative assessment methods mentioned above. To develop such a quantitative assessment method, three aspects needed to be emphasized: (1) the relative role of climate change and human activities should be assessed based on monitoring the dynamics of desertification in a specific period; (2) a common indicator that can be retrieved from remote sensing images needed to be selected to measure the effects of climate change and human activities on desertification; (3) build the relationship between the desertification dynamics and the changing trends of the effect of climate change and human activities measured by the common indicator, based on which the quantitative assessment can be taken. Of the three aspects, the first one indicated the flow of assessment, and the last two aspects were the key points of assessment.

4.2 Selection of a common indicator

Selection of a suitable common indicator is very important for developing the method of assessment, and there are three aspects needed to be specially considered: (1) this indicator should be a core and ecological meaningful indicator in the process of desertification that can reflect the dynamics of desertification; (2) this indicator cannot only reflect the relative role of climate change in desertification, but also can reflect the relative role of human activities in desertification, so the indicator can be used to integrate climate change and human activities into a comparable state; (3) this indicator can be quantitatively retrieved via remote sensing technique, which would make the relative role of climate change and human activities in desertification assessed and expressed in a continuous space. According to the principles mentioned above and some previous studies (Zheng *et al*., 2006; Wessels *et al*., 2008; Prince, 2002), we thought that NPP can be selected as this common indicator. As a core indicator of desertified land ecosystem, NPP can reflect the relative role of climate change and human activities in the process of desertification; besides this, the difference between potential NPP and actual NPP can be used to measure the effect of human activities dominated by the change of land use type and intensity，which had been reported from theoretical and applied aspects in recent years (Wessels *et al*., 2008; Rojstaczer *et al*., 2001; Haberl *et al*., 2002; Haberl *et al*., 2007; O'Neill *et al*., 2007). Meanwhile, the calculation of potential and actual NPP can be modeled by using climate data, remote sensing images and some related empirical parameters, and all of these data can be interpolated in a continuous space. All of these made NPP become a suitable common indicator that can be used to assess the relative role of climate change and human activities in desertification. However, there still existed some limitations for selecting NPP as common indicator, such as the accuracy of NPP retrieval. Large-scale NPP retrieval is mainly done by combining remote sensing images with relevant models, hence the accuracy of NPP retrieval may affect the assessment results of the relative role of climate change and human activities in desertification. So, NPP retrieving model selection and parameters optimization should be paid more attention in the process of assessment for gaining reliable result.

4.3 The process of assessment

When taking an assessment by using this approach, the first step is to monitor the dynamics of desertification in a specific period and build the time series of NPP change induced by climate change and human activities, and all of these data are grid-based in space. In the second step, the establishment of the relationship between the desertification dynamics and the changing trends of NPP induced by climate change and human activities becomes very important to quantitatively assess the relative role of them in a continuous space. The key point in this step is to divide the process of "driving force effect-dynamic response of desertified land" into several scenarios, and the quantitative assessment can be taken in each scenario. As the research conducted by the authors to assess the relative role of climate change and human activities in desertification in Ordos region of China, we divided the process of “driving force effect-dynamic response of desertified land” into several possible scenarios such as desertification reversion dominated by climate change, desertification reversion dominated by human activities, desertification reversion dominated by both climate change and human activities etc., based on which the relative role of climate change and human activities in the process of desertification reversion and development can be quantitatively assessed (Xu *et al*., 2009).

5 Two issues needed to be paid attention in the assessment

5.1 The validation for the results of assessment

The validation of assessment is an indispensible step for quantitative assessing the relative role of climate change and human activities in desertification. However, less researches of quantitatively assessing relative role of climate change and human activities in desertification took a validation for their results, which also indicated that the method used in these studies need to be improved. Owing to the relative role of climate change and human activities in desertification is not an ecological or geographic meaningful variable that can be measured directly, the validation of the assessment results cannot be conducted as other ecological variable by using field investigation. According to the approach provided above, the relative role of climate change and human activities in desertification can be expressed in a continuous space. So, some desertified areas that their driving mechanism can be identified by combining expertise with other auxiliary information could be selected as samples for validation, and the fitness of these samples to the assessment results could be used to validate the quantitative assessment method.

5.2 The scale of assessment

Another important issue that needs to be paid special attention is the scale of assessment. As the process of “driving force effect-dynamic response of desertified land” is the basic research object of ecology and geography, the characteristics of its occurrence, spatio-temporal distribution and mutual coupling are scale-dependant (Prince, 2002; Dong *et al*., 1998). So, the assessment of the relative role of climate change and human activities in desertification should be taken at a specific scale, and the assessment results based on different scales cannot be comparable. The multi-scale assessment conducted by the authors to assess the relative role of climate change and human activities in desertification in Ordos region revealed that there were great differences in the assessments taken at different scales (Xu *et al*., 2010). However, many researches focused on analyzing the dynamics of the landscapes in desertification at different scales from the aspect of landscape ecology, and less researches paid attention to the scale-dependant characteristics when assessing the relative role of climate change and human activities in desertification. According to the approach provided above, the assessment can be taken in a continuous space, which makes it possible to analyze the differences and laws of the assessing results at different scales.

6 Conclusions

A systematical assessment of the relative role of climate change and human activities in desertification is very important to understand the driving mechanism of desertification and effectively combat desertification. Many researches were conducted by using different methods to assess the relative role of climate change and human activities in desertification, and made a remarkable progress. However, there still existed some problems in these previous researches. For the qualitative and semi-quantitative assessment, the subjectivity was obvious and the assessment cannot be easily repeated; for the quantitative assessment, the assessment and its results were always based on administrative regions and less taken and expressed in a continuous space.

To systematically assess the relative role of climate change and human activities in desertification, the assessment method needs to be improved based on previous researches. The results of our research indicated that the method of assessment should be quantitative, and NPP can be selected as a common indicator to measure the effects of climate change and human activities on desertification. Based on this, the relative role of climate change and human activities in desertification can be quantitatively assessed by dividing the process of "driving force effect-dynamic response of desertified land" into several scenarios and building the relationship between the desertification dynamics and the changing trends of NPP induced by climate change and human activities in each scenario.

Meanwhile, the development and application of mathematics, system science and models in ecology and geography make it possible to further improve the method of assessing the relative role of climate change and human activities in desertification. So, the advantages of previous researches should be combined with new method and approach to make the assessment more reliable. Besides, some important issues such as the result validation and assessing scale should be paid attention when taking an assessment, which can make the method of assessment more perfect.

Acknowledgement

The authors would like to thank the anonymous experts for their reviewing our manuscript. We are also very grateful to Wenya Li for correcting the English of this manuscript.

References

Archer Emma R M, 2004. Beyond the "climate versus grazing" impasse: Using remote sensing to investigate the effect of grazing system choice on vegetation cover in the eastern Karoo. *Journal of Arid Environments*, 57: 381–408.

Dong Guangrong, Jin Heling, Chen Huizhong *et al*., 1998. Geneses of desertification in semiarid and subhumid regions of north China. *Quaternary Sciences*, 2: 136–143. (in Chinese)

Dong Yuxiang, 1989. Principal components analysis of influential factors of desertification. *Arid Zone Research*, 4: 34–41. (in Chinese)

Evans J, Geerken R, 2004. Discriminating between climate and human-induced dryland degradation. *Journal of Arid Environments*, 57: 535–554.

Gao Xiaohong, Wang Yimou, Wang Jianhua *et al*., 2005. Analysis on desertification dynamics based on remote sensing and GIS in zone along the Great Wall in northern Shaanxi Province. *Journal of Desert Research*, 25(1): 63–67. (in Chinese)

Geerken R, Ilaiwi M, 2004. Assessment of rangeland degradation and development of a strategy for rehabilitation. *Remote Sensing of Environment*, 90: 490–504.

Haberl H, Erausmann F, Erb K H *et al*., 2002. Human appropriation of net primary production. *Science*, 296: 1968–1969.

Haberl H, Erb K H, Krausmann F *et al*., 2007. Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems. *PNAS*, 104: 12942–12947.

Herrmann S M, Anyamba A, Tucker C J, 2005. Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environment Change*, 15: 394–404.

Li S, Zheng Y, Luo P *et al*., 2007. Desertification in western Hainan Island, China (1959–2003). *Land Degradation and Development*, 18(5): 473–485.

Li Zhenshan, He Limin, Wang Tao, 2006. A method for determining the contribution of natural factors on sandy pasture desertification. *Journal of Desert Research*, 26(5): 687–692. (in Chinese)

Liu Shulin, Wang Tao, 2004. Primary study on sandy desertification in Otindag sandy land and its surrounding regions. *Journal of Soil and Water Conservation*, 18(5): 99–103. (in Chinese)

Ma Shaoxiu, Wang Tao, Xue Xian *et al*., 2007. Dynamic changes of desertification land in the northern Xilinguole grassland. *Journal of Arid Land Resources and Environment*, 21(3): 77–82. (in Chinese)

Ma Y H, Fan S Y, Zhou L H *et al*., 2007. The temporal change of driving factors during the course of land desertification in arid region of North China: the case of Minqin County. *Environment Geology*, 51: 999–1008.

O'Neill D W, Tyedmers P H, Beazley K F, 2007. Human appropriation of net primary production (HANPP) in Nova Scotia, Canada. *Regional Environment Change*, 7: 1–14.

Prince S D, 2002. Spatial and temporal scales for detection of desertification. In: Reynolds J F, Stafford Smith D M (eds.). Global Desertification: Do Humans Cause Deserts? Berlin: Dahlem University Press, 23–40.

Rojstaczer S, Sterling S M, Moore N J, 2001. Human appropriation of photosynthesis products. *Science*, 294: 2549–2552.

State Forestry Administration. The third Communique of desertification and sandy desertification in China. 2007, http://www.gov.cn/ztzl/fszs/content_650487.htm.

Sun Danfeng, 2005. Analysis of socio-economic driving forces on land desertification at Minqin county in Gansu Province in 1988–1997. *Transactions of the CSAE*, z1: 131–135. (in Chinese)

Wang Tao, 2003. Study on sandy desertification in China: 2. Contents of desertification. *Journal of Desert Research*, 23(5): 477–482. (in Chinese)

Wang Tao, 2004. Study on sandy desertification in China: 4. Strategy and approach for combating sandy desertification. *Journal of Desert Research*, 24(2): 115–123. (in Chinese)

Wang Tao, Wu Wei, Zhao Halin *et al*., 2004. Analyses on driving factors to sandy desertification process in Horqin region, China. *Journal of Desert Research*, 24(5): 519–528. (in Chinese)

Wang Tao, Zhu Zhenda, 2003. Study on sandy desertification in China: 1. Definition of sandy desertification and its connotation. *Journal of Desert Research*, 23(3): 209–214. (in Chinese)

Wang X M, Chen H F, Dong Z B, 2006. The relative role of climatic and human factors in desertification in semiarid China. *Global Environment Change*, 16: 48–57.

Wang X M, Zhang C X, Hasi E *et al*., 2010. Has the Three Norths Forest Shelterbelt Program solved the desertification and dust storm problems in arid and semiarid China? *Journal of Arid Environments*, 74: 13–22.

Wessels K J, Prince S D, Malherbe J *et al*., 2007. Can human-induced land degradation be distinguished from the effects of rainfall variability? A case study in South Africa. *Journal of Arid Environments*, 68: 271–297.

Wessels K J, Prince S D, Reshef I, 2008. Mapping land degradation by comparison of vegetation production to spatially derived estimates of potential production. *Journal of Arid Environments*, 72: 1940–1949.

Xu D Y, Kang X W, Liu Z L *et al*., 2009. Assessing the relative role of climate change and human activities in sandy desertification of Ordos region, China. *Science in China* (*Series D*), 52: 855–868.

Xu D Y, Kang X W, Zhuang D F *et al*., 2010. Multi-scale quantitative assessment of the relative roles of climate change and human activities in desertification: A case study of the Ordos Plateau, China. *Journal of Arid Environments*, 74: 498–507.

Xu Xiaoling, Yan Junping, 2005. Research on quantitative relations between human factors and desertification in northern Shaanxi sandy area. *Journal of Arid Land Research and Environment*, 19(5): 38–41. (in Chinese)

Zhang Chunlai, Dong Guangrong, Zou Xueyong *et al*., 2005. Contributing ratios of several factors to the steppe desertification in Guinan, Qinghai Province. *Journal of Desert Research*, 25(4): 511–518. (in Chinese)

Zhang Dengshan, 2000. Quantitative analysis of influential factors on land desertification in Qinghai Gonghe Basin. *Journal of Desert Research*, 20(1): 59–62. (in Chinese)

Zhang Yushu, Wang Lixin, Zhang Hongqi *et al*., 2003. Influence of environmental factor changes on desertification process in Shule River. *Resources Science*, 25(6): 60–65. (in Chinese)

Zheng Y R, Xie Z X, Robert C *et al*., 2006. Did climate drive ecosystem change and induce desertification in Otindag sandy land, China over the past 40 years? *Journal of Arid Environments*, 64: 523–541.

Zika M, Erb K, 2007. Net primary production losses due to human-induced desertification. Second International Conference on Earth System Modelling (ICESM), 1.