Assessment and monitoring of desertification using satellite imagery of MODIS in East Asia

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ABSTRACT

The desertification in Northwestern China and Mongolia shows the result of conflicts between economic development and natural conservation. Many researches have proven the desert areas are growing in these regions. The variations of bi-weekly NDVI satellite images are used as one of the parameters to evaluate the vegetation dynamics over large scale studies. In this study, remotely sensed satellite images are conducted to provide multi-temporal vegetated and non-vegetated areas in order to assess the status of desertification in East Asia. Spatial data derived from these satellite images are applied to evaluate vegetation dynamics at regional scale to find out the hot spot areas vulnerable to desertification. The results show that the desert areas are mainly distributed over southern Mongolia, central and western Inner-Mongolia, western China (the Taklimakan desert). The desert areas were expanded from 2000 to 2002, were shrunk in 2003, and were expanded from 2003 to 2005 again. The hot spot areas of desertification are mainly distributed over southeastern Mongolia and eastern Inner-Mongolia. The results will help administrators to refine the planning processes in defining the boundaries of protected areas and will facilitate to take decision of the priority areas for conservation of desertification.

Keyword: desertification, NDVI, monitoring, vegetation, remote sensing

1. INTRODUCTION

Desertification is widely recognized as a serious threat to arid and semi-arid environments which cover over 40% of the global land surface and are populated by approximately 1 billion humans[1]. Overgrazing and improper agricultural practices are the main human-made causes of desertification in semi-arid zones. From previous studies, desertification or land degradation are related to a variety of factors including improper agricultural practices, livestock overgrazing, over-reclamation, mining, fire management schemes, recreation practices, deforestation, urbanization, human population pressure, severe soil loss, low vegetative cover, and the introduction of exotic species[2-5]. In developing countries of the

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world, population growth and economic development continue to place increasing pressure on environment, particularly in arid and semi-arid areas. Thus, desertification has become an important, urgent global environmental problem. In China and Mongolia, there were more environmental pressures from the developing economic and rapid population growth.

The occurrence of dust storms induced by wind erosion can be considered as an indicator of desertification[6]. Recently, dust storms have also been an important environmental problem in East Asia. Batjargal et al. (2006) discussed the environmental degradation in Mongolia and the social, economic, and atmospheric impacts of dust storms in the sink areas[7]. The main dust sources over East Asia are the Taklimakan desert, the central Gobi desert, and the western part of inner-Mongolia plateau[8-10]. Xuan et al. (2000) found that springtime is the worst dust-emitting season over northern China[8]. Moreover, Xuan and Sokolik (2002) demonstrated that a combination of extreme aridity and strong winds is a key factor governing the dust emission there[9]. Furthermore, there are an important annual and inter-annual variability of dust emission between 100 Mt yr^{-1} and 460 Mt yr^{-1} [10]. However, dust storms occur mainly during the months of dry season over the regions in Mongolia and northern China[7,12]. In particular, some aerosols were from different sources, such as widespread boreal forest fires persisted in Eastern Asia ranging from eastern Siberia to northern and eastern China, Korea, and Japan[13]. In particular, simulations of Asian dust emissions over the past 43 years show that meteorology and climate have had a greater influence on dust emissions[14]. Furthermore, Wang et al.(2006) suggested that human activities may not be mainly responsible for the rapid desertification. They found two climatic factors related to sand transport (drift potential and the frequency of sand-driving wind) had a stronger impact on desertification in semiarid northern China[15]. Xu(2006) found that the frequency of sand-dust storms may be effectively decreased by reducing the area of cultivated land and restoring the natural steppe vegetation in ecologically fragile areas in arid and semi-arid climates[6]. However, deserts still are the main sources of dust emission. Therefore, governments and scientists should pay attention to the problem of desert spread (desertification) over the regions of arid and semi-arid environments.

Mongolia and China are the most seriously affected countries of dust storm in Asia. The governments have made great efforts to combat desertification. Yang et al.(2005) reviewed desertification assessments in China and pointed out that future assessment should include a participatory-based hierarchical framework and an early warning system for desertification[16]. Moreover, Veron et al.(2006) showed that desertification assessment has shifted from simple appraisals of the inter-annual movement of desert boundaries to complex multivariate field surveys, to practical methodologies based on indicators of ecosystem functioning, such as rain use efficiency[1].

Besides the serious situation of desertification over East Asia, the governments in East Asia have made great efforts to combat the environmental problems coming with desertification. In addition, as the desert areas continue to expand in northern China[16], the governments have an urgent need to renew the spatial distribution of desert area and in-danger area of desertification. The remotely sensed images from the Modis instrument onboard Terra have applied to monitoring the changes in the desert boundaries during the period from August 2000 to August 2005. Therefore, accurate assessment of the status, change, and trend of desertification will be useful and important in developing regional actions to prevent and eradicate the problem of desertification. The purpose of this study is to monitoring the cover area of desertification in East Asia and find out the trend of desert spreading.

2. METHODOLOGY

2.1 NDVI and data proceeding

The NDVI is a commonly used vegetation index derived from remotely sensed measurements of electromagnetic energy in the red and near-infrared spectral regions. The concept of vegetation indices used to depict the large scale distribution and phenological changes of vegetation cover over particular is that green vegetation absorbs and reflects more radiance in the visible red and near infrared wavelength. Most spectral vegetation indices are based on a certain combination of the ration between the red waveband, R, where chlorophyll causes considerable absorption of incident light, and the NIR wavelengths, which corresponds to the zone of maximum reflectance of incoming radiation by healthy green leaves due to their internal mesophyll structure. NDVI utilizes differences in leaf absorptions in the red and near-infrared bands[17-20]. The advantage of NDVI is that it has less influence from sun angle and illumination and provides relatively reliable information about vegetation cover dynamics. Therefore, we used NDVI to depict the desert cover areas and investigate the spatial distribution of green cover in East Asia. The NDVI is a normalized ratio of the NIR and red bands,

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}} \tag{1}$$

where ρ_{NIR} and ρ_{red} are the surface bidirectional reflectance factors for their respective MODIS bands. This equation produces NDVI values which lie in the range of -1.0 to +1.0 with denser and/or healthier vegetation having higher positive values.

2.2 Estimating the boundary between desert and grasslands

From previous studies, it has been proven that seasonal changes in NDVI can be related to vegetation phenological stages. Thus, NDVI has been used in this study for monitoring the physiological and spatial distribution of vegetation from remote sensing data. The study conducted near the eastern edges of the Gobi desert has shown that the NDVI of desert/desert steppe are always lower than 0.1[21]. Furthermore, the results are observed from the mean time-series NDVI from 1982 to 1990 for the three types of grasslands. For this reason, the NDVI value, 0.1, in this region is useful for distinguishing non-vegetated landcover types, such as bare land, desert, etc., from vegetated landcover types. Therefore, the threshold has to be used to define the desert/ non-desert boundary in the study area. It is important to point out that it was not assumed that the NDVI value lower than 0.1 in the area means that the area had converted to a desert, but that it has undergone desert-like conditions in that particular time period.

2.3 Hot spot assessment of desertification

The months of July through September were selected to represent the high peak characteristics of NDVI of the growing season in East Asia, even though the high peak of the growing season may vary across the region from year to year. In order to reduce the amount of data to be examined, we created a long-term NDVI climatology (2000-2005). The year to year variability in the NDVI patterns was examined by calculating yearly NDVI anomalies as follows:

$$NDVI_{\sigma} = \left(\frac{NDVI_i - NDVI_{\mu}}{NDVI_{\mu}} \right) * 100 \tag{2}$$

where $NDVI_{\sigma}$ is the result indicated the hot spot areas in the year i, $NDVI_{\mu}$ is the mean summer maximum NDVI between 2000 and 2005. The positive results indicate the areas have higher greenness than average status. The negative results indicate the areas have lower greenness than average status. The high negative results show the areas are in danger of land degradation, especially in danger of desertification.

3. DATA

The moderate resolution imaging spectroradiometer (MODIS) instruments have a wide swath and give a near global coverage in 1 to 2 days. It's a powerful resource satellite used to assess and monitoring the spatial patterns of land surface, functions of the environment and the interactions between the atmosphere, the ocean, and the biosphere. The MODIS instrument onboard the Terra satellite has been providing NDVI bi-weekly maximum composites over land since February 2000. In addition, the MODIS instrument onboard Aqua has been providing the NDVI composites since July 2002. The images from MODIS on board Terra were used in this study. Thus, the images of growing season were analyzed and the period was from 2000 to 2005. The remotely sensed data used in this study are the MODIS/Terra Vegetation Indices 16-Day L3 Global 1km SIN Grid.

The area of interest is located between 65ºE and 135ºE, and 20ºN and 60º (Fig. 1). The main land cover type classified according to the 2001 MODIS images is mixed forests, which covers more than 17% of the region and are mainly distributed over mid Siberia, eastern Siberia, Korea, and Japan. The landcover types of grasslands, croplands, and open shrublands cover 16.0, 13.1%, and 13.3% over the region. Desert areas, which are the main sources of dust emissions in East Asia, cover 12.6% of this region. This land cover map provides a near-latest land cover types that will be used for comparison of desert cover distributions with those retrieved from satellite NDVI images during the period from year 2000 to year 2005.

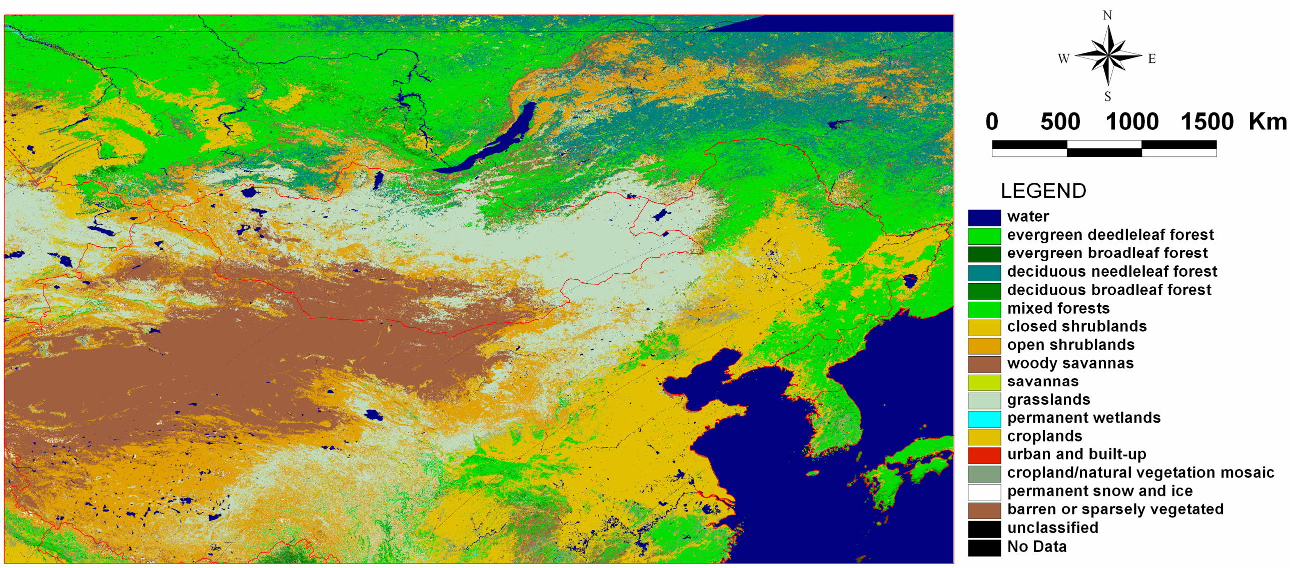

Figure 1. Land-cover distributions over northern China and Mongolia. The land cover data were classified and released by the MODIS terrain science team. The 2001 MODIS land cover data are available as IGBP classes. There are lots of deserts distributed from the Taklimakan desert, the central Gobi desert, and the western part of inner-Mongolia plateau. The deserts are the main sources of dust emission in East Asia.

4. RESULTS

4.1 Inter-annual variations of desert area

The spatial distributions for East Asia region are shown in Fig. 2. These series of images show the desert areas for selected growing seasons during the 2000-2005 period. In 2000 (Fig. 2a), most of the desert areas are distributed over southern Mongolia, central and western Inner-Mongolia, western China (the Taklimakan desert). In contrast Fig. 2b shows the desert areas in 2001 are expanded. The expanded desert areas are mainly distributed over southern Mongolia.

The desert areas distributed over northwestern India are expanded in 2002, shrunk in 2003, and expanded in 2004 and 2005 again. The patterns of desert areas in 2004 are similarly observed across the whole region during the 2005 growing season. The administration of India should pay attention to these regions to combat with desertification. The desert areas distributed over southern Mongolia and eastern Inner-Mongolia were expanded from 2000 to 2002, were shrunk in 2003, and were expanded from 2003 to 2005. In 2005, the desert areas were larger than the other years. Fig. 4 shows the spatial patterns of areas vulnerable to desertification during the period between 2000 and 2005. These maps are useful to assess the areas in danger of desertification. The time-series images indicate the similar trends with the maps of desert areas.

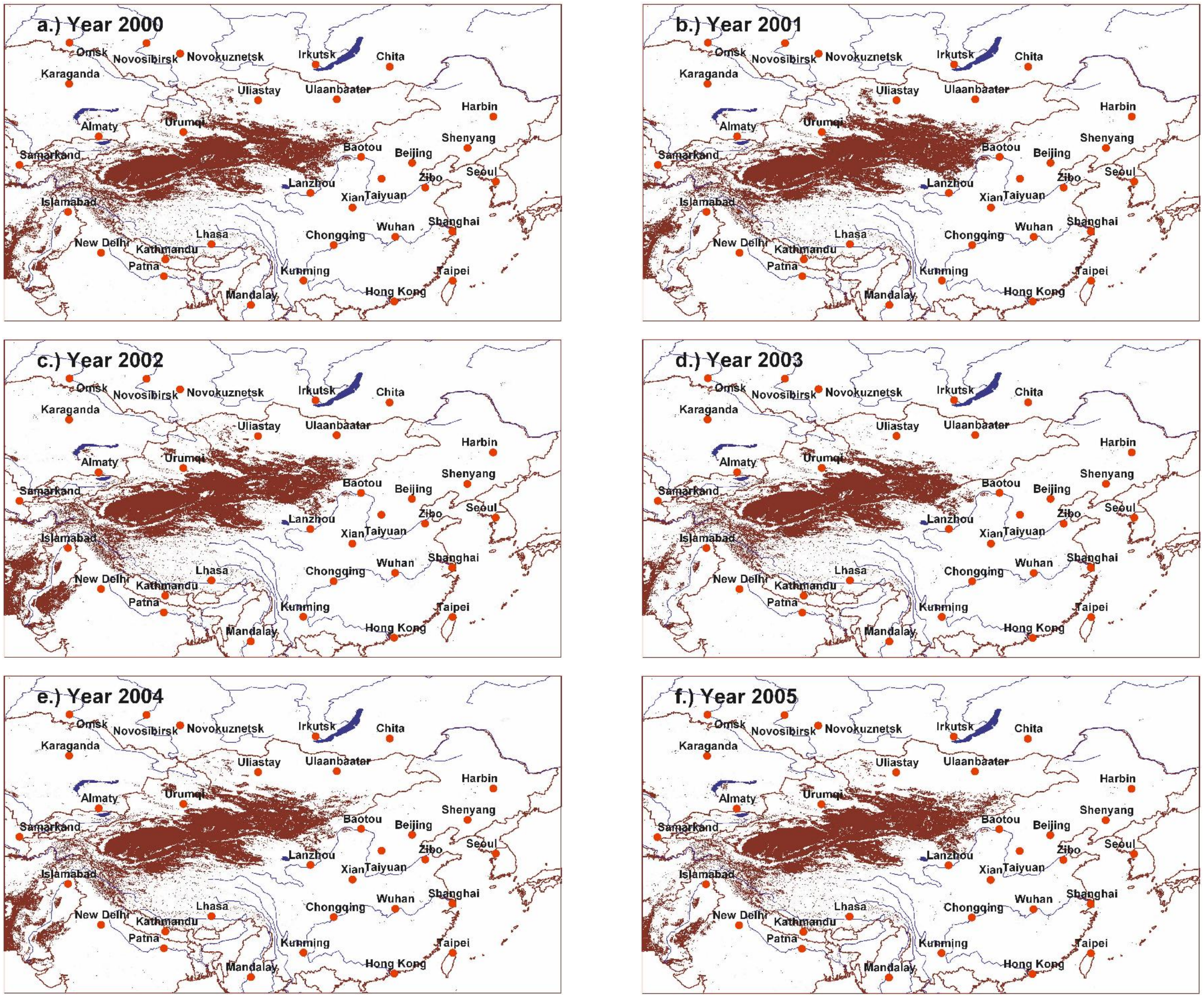

Figure 2. The spatial patterns show desert distributions over East Asia between 2000 and 2005. TERRA/MODIS

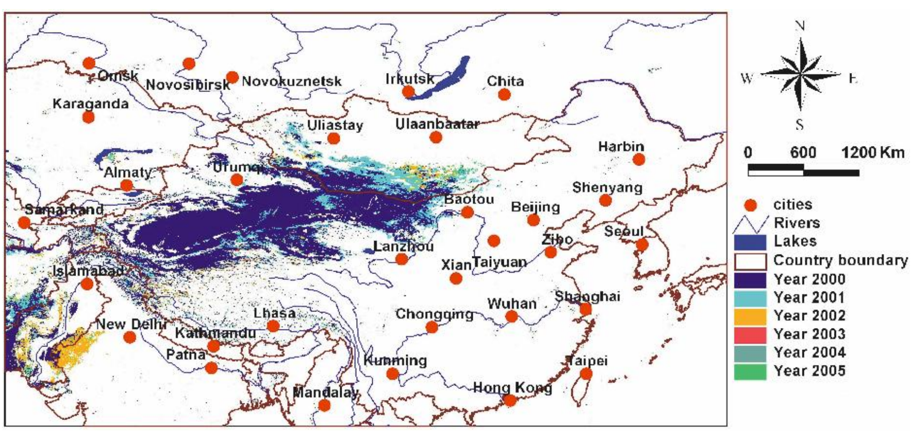

Figure 3. The comparison of desert areas between 2000 and 2005. The map shows the spatial distribution of desert in East Asia. The desert areas of year 2001 were expended over southern Mongolia. TERRA/MODIS

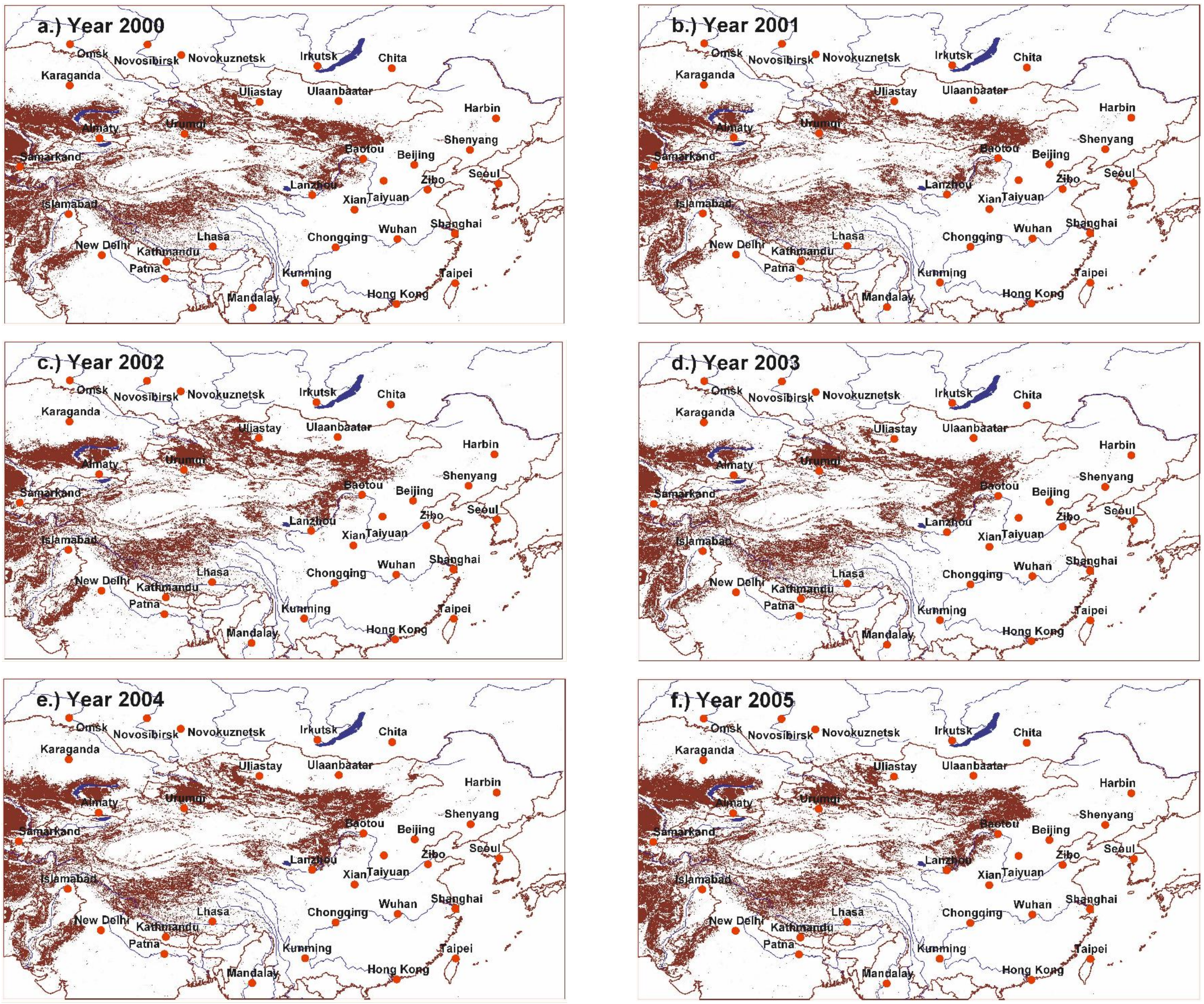

Figure 4. The spatial patterns show the areas vulnerable to desertification between 2000 and 2005. TERRA/MODIS

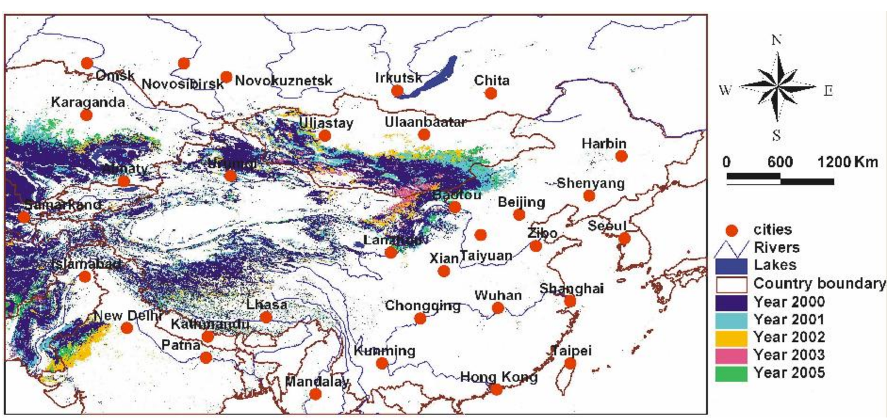

Figure 5. The map shows the main expanding areas vulnerable to desertification from 2000 to 2005 in East Asia. The areas vulnerable to desertification were mainly expended over southeastern Mongolia in 2001 and over northwestern India in 2002. TERRA/MODIS

4.2 Spatial distribution and Temporal change of NDVI

NDVI values are distributed unevenly on the image coverage of East Asia (Fig. 6). The NDVI lowest values (lower than 0.1) dominate in western China part and ranged from western China to southern Mongolia. These areas are the main parts of the Taklimakan desert, the Gobi desert, and the Mongolia plateau. Lower NDVI values ranging from 0.1 to 0.29 dominate in southwestern china, southern Mongolia. The NDVI values ranging from 0.3 to 0.49 are mainly distributed in northern Mongolia, central Asia, and the belt between Inner-Mongolia and northern China. With some variations from year to year, the spatial distribution of NDVI values lower than 0.1 is in accordance with the boundary and extent of dominant desert districts of East Asia. Furthermore, the time-series maps of NDVI have provided the spatial patterns of vegetation dynamics.

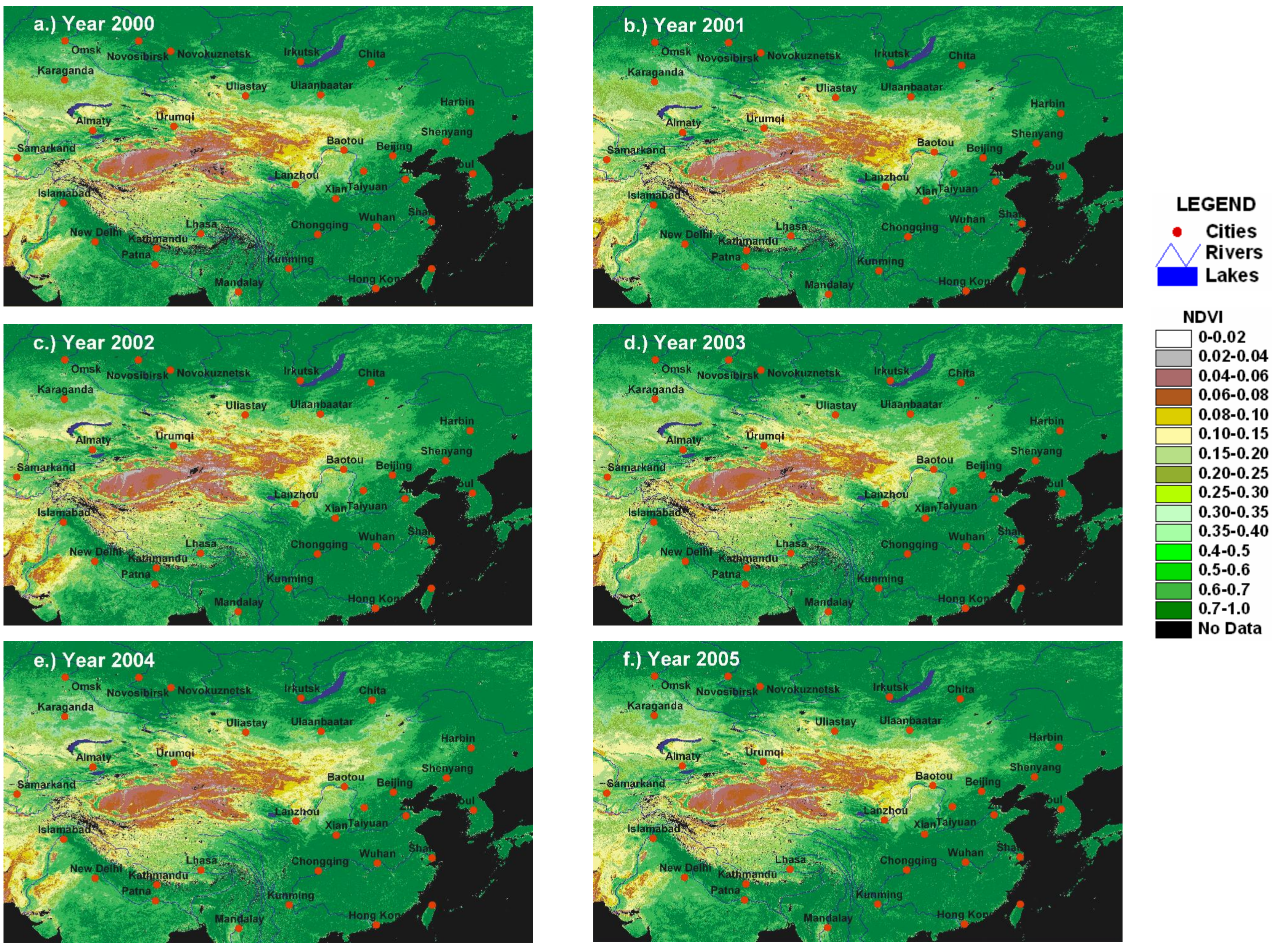

Figure 6. Time-series NDVI summer images between 2000 and 2005, East Asia. Terra/MODIS

4.3 Hot spot assessment of desertification

The zonal characteristics of negative $NDVI_\sigma$ in 2005 show the spatial patterns of hot spot areas vulnerable to desertification (Fig. 7). The negative $NDVI_\sigma$ means that the pixels in maximum summer NDVI of year σ is lower than the average of maximum summer NDVI. Therefore, the areas in red colors called the hot spots in danger of desertification, especially the $NDVI_\sigma$ values ranging between -60% and -40%. The hot spots with values ranging between -60% and -40% mainly distributed over southeastern Mongolia and eastern Inner-Mongolia. Some hot spots distributed over northwestern India and central Asia. The areas with green colors indicate that the pixels in maximum summer NDVI of year σ is higher than the average of maximum summer NDVI. There are some areas with green colors distributed over northwestern and northeastern Mongolia.

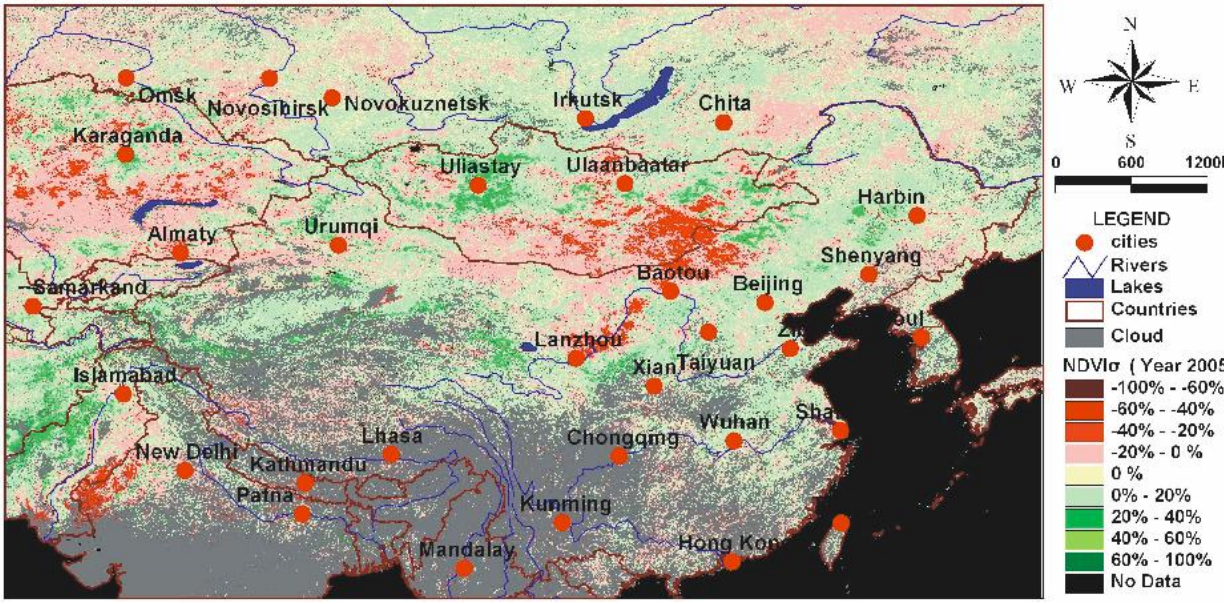

Figure 7. Hot spot images of the year 2005, East Asia. The map shows the areas which is in danger of desertification in red colors and the areas which have growing greenness in green colors.

5. CONCLUSIONS

Satellite measurements of East Asia vegetation dynamics during the last 6 years have provided a comprehensive picture of the patterns of desert inter-annual variation. During the period between 2000 and 2005, most of the desert areas are stable and mainly distributed over southern Mongolia, central and western Inner-Mongolia, western China (the Taklimakan desert). Some desert areas over southern Mongolia were expanded in 2001. In northwestern India, The spatial distributions of desert and areas vulnerable to desertification derived from satellite images during the period between 2000 and 2005 have provided precise locations. The main areas vulnerable to desertification are distributed over . The maps will help governments to combat with desertification effectively. The new attempt of hot spot assessment shows the similar patterns with the image of areas vulnerable to desertification.

Our analysis using NDVI data is only based on a 6-year reference average from 2000-2005, which may not be representative of the typical 30-year averages used in historical vegetation studies. Therefore, the result of spatial distribution in areas vulnerable to desertification should be used carefully in policy making, ecosystem restoration, and environmental monitoring. Further studies combined satellite images from NOAA AVHRR and TERRA MODIS will help in understanding the long-term changes in desertification over East Asia and in recognizing the actual distributions of areas vulnerable to desertification.

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