Land Degradation Due to Salinization in Arid and Semi-arid Regions with the Aid of Geo-information Techniques

Mushtak T. Jabbar  CHEN Xiaoling

Abstract  This study applied a computerized parametric methodology to monitor, map, and quantify land degradation by salinization risk detection techniques at a 1:250 000 mapping scale using geo-information technology. The northern part of the Shaanxi province in China was taken as a case. Multi-temporal remotely sensed materials of both Landsat TM and thematic maps (ETM+) were used as the bases to provide comprehensive views of surface conditions such as vegetation cover and salinization detection. With ERDAS ver. 9.1 software, the Normalized Differential Salinity Index (NDSI) and Salinity Index (S.I.) were computed and then evaluated for land degradation by salinization. Arc/Info ver. 9.2 software was used along with field observation data (GPS) for analysis. Using spatial analysis methods, results showed that 19 973.1 km² (72%) of land had no risk of land degradation by salinization, 3 684.7 km² (13%) had slight land degradation by salinization risk, 2 797.9 km² (10%) had moderate land degradation by salinization risk, and 1 218.9 km² (4%) of the total land area was at a high risk of land degradation by salinization. The study area, in general, is exposed to a high risk of soil salinization.

Keywords  geo-information techniques; land degradation; soil salinization indices

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Introduction

Desertification refers to land degradation in arid environments and is a major economic, social, and environmental problem[1]. Land degradation is important to the international community, because it affects food security, international aid programs and national economic development strategies[1]. Land degradation has many definitions[2], but it is basically a reduction in the biological productivity of the land[3,4]. If the Earth has greened over the last twenty years, this knowledge should have significant implications for studies on land degradation, because the greening could run counter to many short-term and localized land degradation studies. In light of recent scientific developments in the understanding of environmental change, we ask what is land degradation in the context of the global greening phenomenon?

This paper has three foci: (1) to scale 30 m² pixel-level vegetation index, and soil salinization indices data to national, regional and local aggregate levels, (2) to provide a methodology for change detection of land degradation and land greening in the northern part of the Shaanxi province, (3) to combine both approaches to detect land degradation and greening.
within all aggregate levels. We begin with a short review of various approaches for land degradation measurement with satellite remote sensing imagery and present our ideas for change detection. The aggregate scaling and change detection analyses were performed on nearly seven counties in the northern part of the Shaanxi province. Next, we present our findings for pixel and aggregate-level environmental change. We then compare our findings for pixel-level change detection of land degradation and greening to the findings of past work on the greening of the location study. This comparison is completed, so that our approach to change detection can be standardized with the results of past studies. If our change detection methods are similar to past studies, then our aggregate-level change detection should be comparable to that of the pixel-level assessment. Finally, we present the application of this study as a way to alleviate some methodological issues in land change science.

1 Geo-information of land degradation

Prince[5] reviews various methods used in geo-information science to monitor land degradation. Of these approaches, the rain use efficiency model[6-9] is the most useful method to monitor small-scale land degradation in arid and semi-arid environments. At finer spatial scales, other methods have been developed to accommodate factors such as soil type, elevation, and distance from water source, etc.[3,10,11], which contribute to the spatial variability of biological productivity in the context of the specific locality. Therefore, monitoring land degradation by satellite remote sensing imagery is scale dependent. Prince[5] requires more detailed parameterization at increasing spatial scales. What seems to be missing in many of these approaches in monitoring land degradation is that models can calculate differing amounts of land degradation in a given area, but few empirical analyses have sought to determine the threshold that constitutes significant amounts of land degradation in the full range of modeled amounts of land degradation.

The emphasis of this paper is not the modeling aspect of land degradation, but rather to develop an empirical methodology for change detection of land degradation and land greening in the study location. No modeling procedures have been developed to estimate land degradation in the study. We assume a reduction in the productivity of the land to be a universal definition for land degradation, and should be applicable from the global to the local context. Assessment of positive and negative amounts in vegetation cover and salinization area change will yield measurements for differing amounts of land degradation or greening. However, the issue here is what amount of vegetation cover and proportion of salinization area change should be considered as significant in terms of land degradation or land greening during the study period, especially since the Earth greened. To account for the full range of vegetation cover and proportion of salinization area change, it is necessary to derive a standardized amount of annual vegetation and soil salinization indices change. This is necessary to quantitatively test for normal amounts of vegetation cover and proportion of salinization area change in the northern part of Shaanxi province, so that we can detect significant amounts of land degradation and land greening.

In China, the main types of desertification can be classified as follows: sandy desertification caused by wind erosion, land degradation by water erosion, soil salinization and other land degradation causes[12]. According to the conception of desertification in China, the total desertified land had reached to 861 600 km² by the end of 1987, accounting for 8.97% of the total land of China. Table 1 shows the areas of desertified land, which was caused by different processes in China[13]. There are about 20% or a total 100 million km² of farmland in China that have been more or less threatened by the salinization at present, and about 69 000 km² land has been salinized by the end of 1987, which was mainly distributed in the arid and semi-arid regions of Northwest China and sub-humid regions of the North China Plain[13,14]. Soil salinization is mainly caused by natural and agricultural factors. Climate, natural drainage, topographic properties, geological structure, and parent material are the natural factors, while improper irrigation methods, water quality, insufficient
drainage, and poor land management are agricultural factors\textsuperscript{15,16}. The selection of an irrigation method is related to salinity. The method that is best adapted in any particular case depends upon several conditions: the crop to be grown, topography, soil characteristics, availability of water, soluble-salt content of the water, and salinity status of the soils\textsuperscript{16}. Understanding the changes of salt in the soil profile is a prerequisite for devising appropriate management strategies to increase soil productivity in salinizing regions. In the northern part of the Shaanxi province, a slight decrease was observed in the structural stability and aggregation indices after irrigation. However, the decrease in hydraulic conductivity was significant. Moreover, salinity significantly increased in the soil and there were no changes in clay mineral content\textsuperscript{17}. There is a clear need for the development of cost-effective and quantitative salinity monitoring techniques.

The objective of this study was to monitor, map, and estimate land degradation by soil salinization by using “3S” technology and a change detection technique in the northern part of Shaanxi province, China.

\begin{table}[h]
\centering
\begin{tabular}{lcc}
\hline
\textbf{Types of desertification} & \textbf{Area / km}^2 & \textbf{\% of total} \\
\hline
Wind erosion & 379 600 & 44.1 \\
Water erosion & 394 000 & 45.7 \\
Salinization & 69 000 & 8.3 \\
Engineering construction & 19 000 & 1.9 \\
Total & 861 600 & 100.0 \\
\hline
\end{tabular}
\caption{Areas of desertification land by different process in China}
\end{table}

2 Materials and methods

2.1 Materials

The study area, located in the northern part of the Shaanxi province, lies within longitude 108° 33’ to 111° 24’ E and from latitude 36° 97’ to 39° 58’ N with a total area of 27 702 km\(^2\), accounting for 17.5% of the total Shaanxi province (Fig. 1). To study the development of land degradation, the counties of Jingbian, Hengshan, Mizhi, Jiaxian, Yuyang, Shenmu and Fugu have been selected as the study areas. The counties are situated in the northern part of Shaanxi province. The present population density is an average of 45 persons/km\(^2\). Over the last decade, population in the area has grown at a rate of 18 300 per annum. This area is a typical agro-pastoral region and an important energy and mineral base in China. Geomorphologically, it has multiple hierarchical zones dominated by aeolian landforms. Its climate varies from arid and semi-arid to sub-humid with dry and cold winters. Underground water resources are relatively rich. Natural vegetation transforms from desert and desert steppe to forest steppe. The transitional nature of its ecology implies that the environment in the region is diverse, complex, and vulnerable. Presently, severe land degradation occurs mainly in the form of desertification. Overall, 88.5% of land has been desertified to varying levels, Yulin county is the most desertified at 96% of the area\textsuperscript{17}.

The images from Landsat TM and thematic map ETM were acquired in October, 1987 and in October, 1999. Table 2 shows the characteristics of the remote sensing data, which has been used in this research. All the five thematic layers were generated in GIS environment at a scale of 1:250 000. The softwares packages used for this study were Arc/Info, ArcView, ERDAS, and ERmapper.

\begin{table}[h]
\centering
\begin{tabular}{llc}
\hline
\textbf{Location} & \textbf{Satellite sensor} & \textbf{*WRS Path/Row} \\
\hline
Yuyang county & Landsat-5 TM and Landsat-7 ETM & 127/33 \\
Jingbian county & Landsat-5 TM and Landsat-7 ETM & 127/34 \\
Dingbian county & Landsat-5 TM and Landsat-7 ETM & 128/34 \\
\hline
* WRS is the Worldwide Reference System (WRS), which is a global notation system for Landsat data.
\end{tabular}
\caption{Remote sensing data that used in the study}
\end{table}
2.2 Methods

2.2.1 Laboratory studies and field work

Representative soil samples from the study location in the northern part of Shaanxi Province (Jingbian, Hengshan, Mizhi, Jiaxian, Yuyang, Shenmu and Fugu) were collected with their GPS locations from 40 field sites with soil types typical of each county polygon. The ground water table was measured at each sampling site. Selected physical and chemical properties of the soils are listed in Table 3. These properties were measured according to the procedures of Black[18]. Values for average meteorological data were obtained from local meteorological stations according to the information recorded during the period 1987–1999.

2.2.2 Satellite data and preprocessing of image

Landsat TM images acquired in October 1987 and a Landsat ETM image from October 1999 were used for detection of salinization risk and vegetation cover changes. The ETM and TM sensors consisted of detectors, which produced signals proportional to the average amount of light reflected from an area 30 × 30 m, which correlated to the geometrical resolution of a Landsat TM sensor. Random distortion needed to be corrected by the analyst through the selection of a sufficient number of ground control points (GCP) with correct coordinates.

Through the use of a rectification algorithm for the image and/or vector, the column and row coordinates of the image could be fitted to the geodetic datum WGS84 and map projection NUTM49 coordinate system built into the vector using the linear method. The resampling method chosen was nearest-neighbor, which preserved the original reflectance value. Fifty ground control points were selected on the images, primarily on the clearly visible river. The points were spread quite evenly throughout the image, allowing for adequate control. Image software allowed for easy zooming to assist in point selection. The points were registered in the header file of the image for later rectification. Once all ground control points were compiled, error checking was used to gauge the efficiency of the points used. The RMS errors for linear method of rectification were examined with varying accuracies, all approximately 0.50 m in displacement error[19]. Since salinization detection methods were developed into indices, there was no need for an investigation of principal components or edge detection during this research.

2.2.3 Post processing of the image and indices

Two salinity indices based on the concept of spectral response to salt-affected soils were calculated. It is noted that spectral response in terms of digital number (DN) of salt-affected soils is relatively higher than other categories in band-1 (B1) and band-3 (B3). The following two salinity indices were used:

1) Salinity Index (S.I.). This index proposed by Tripathi[20] was applied, which gives relatively adequate results in the re-classification of salt-affected soils. The S.I is calculated as:

\[
S.I = \left[ \frac{1}{2} \times \left( \frac{Band1 \times Band3}{Band1 + Band3} \right) \right]^{\frac{1}{3}}
\]  

2) Normalized Differential Salinity Index (NDSI). This index (NDSI) is just the reverse of the NDVI index for vegetation[20]. The NDSI is basically the difference between the red and near infrared band combination divided by the sum of the red and near infrared band combination. The algorithm used was:

\[
NDSI = \frac{(Band3 - Band4)}{(Band3 + Band4)}
\]

Reflectance variations of vegetation on the image are attributed to the different species of vegetation and their densities, which together provide evidence of shallow ground water table conditions and saline agricultural areas. Favorable growth conditions prevail in regions where the water table is situated below the area of influence of evapotranspiration, that is, within 10 m depth[21]. An indication of whether scanty vegetation in an area is due to the depth of the water table or salinity can be investigated using Normalized Differential Vegetation Index (NDVI) which easily grasps the state of vegetation. NDVI was the most common form of vegetation index[22], and was basically the difference between the red and near infrared band combination divided by the sum of the red and near infrared band combination or:

\[
NDVI = \frac{(NIR - R)}{(NIR + R)}
\]
The maps of irrigation canals and surface drainage networks were digitized in the GIS environment. Some discrepancies of mismatching were found when overlaid on the geo-referenced image. These layers were then corrected with the help of topographic maps and images. It was presumed that the topographic sheets could be the most reliable source of information. Buffering analysis along canal and drain channels was performed for a 1000 m corridor to see the salinity impact on productivity in terms of vegetation vigor. To calculate vegetation cover percent from NDVI, the model developed by Porevdoj[22] was used:

$$\text{Vegetation Cover (\%) = } 4.337 \times \text{NDVI} - 3.733 \times \text{NDVI} + 1987 \times 161.968 \times \text{NDVI} - 720.9$$  (4)

| Physical and Chemical | County name | Jingbian | Hengshan | Mizhi | Yuyang | Jiaxian | Shenmu | Fugu |
|-----------------------|-------------|----------|----------|-------|--------|---------|--------|------|
| Sand / (g•kg$^{-1}$)  |             | 910.0    | 820.5    | 240.0 | 930.9  | 690.2   | 900.3  | 720.9|
| Silt / (g•kg$^{-1}$)  |             | 49.86    | 98.70    | 489.6 | 10.2   | 150.6   | 20.2   | 180.3|
| Clay / (g•kg$^{-1}$)  |             | 40.12    | 80.80    | 270.4 | 40.8   | 150.1   | 70.4   | 80.7 |
| Texture               |             | Sandy    | L.Sand   | Silty L. | Sandy | Sandy L. | Sandy L. | Sandy L. |
| Bulk D. / (g•m$^{-3}$)|             | 1.66     | 1.43     | 1.21   | 1.68   | 1.52    | 1.62   | 1.53 |
| pH                    |             | 7.29     | 7.20     | 7.80   | 7.8    | 7.7     | 7.8    | 7.9  |
| O.M / (g•kg$^{-1}$)   |             | 0.85     | 1.85     | 3.70   | 0.19   | 0.40    | 0.29   | 0.51 |
| EC / (dsm$^{-1}$)     |             | 3.95     | 4.20     | 4.40   | 3.80   | 4.29    | 3.58   | 3.99 |
| CaCO$_3$ / (g•kg$^{-1}$)|         | 162.5    | 125.6    | 120.2  | 110-280| 80-200  | 100-250| 100-250|

3 Result and discussion

3.1 Soil salinization detection

To detect changes of salinity level in the study area, salinization index maps were established using the integrated GIS approach with satellite images for 1987 and 1999. Fig.2 shows a significant increase of salt accumulation during the 12-year period. After 1990, human activities increased salinization by excessive application of irrigation water without adequate drainage facilities[13,20]. Fig.2 and Fig.3 reveal that salinization increased with time. Most soils showed a change in salinization from none to slight, slight to moderate, and moderate to strong saline. Strong saline soils were specifically located in the southern part of the study area in 1987, but the same level of salinity also appeared in the middle and northern part in 1999. Almost all strongly saline soils were located at the irrigated area (Shaanxi department of Land and Resources report)[17]. According to the Shaanxi Department of Land and Resources reports series referred by Liu[17], the most salinization from the location of the soils are in the lowest parts (about 300 m above sea level) of the study area. This results in shallow saline ground water and accumulation of salt at the highest level, due to the capillary movement of the water from extensive evaporation from the soil surface (Fig.2). The use of temporal soil data to determine salinity of agricultural lands has always been thought of as a fast and cost-effective method to monitor salt problems affecting crop yields. The use of RS&GIS for monitoring salinity has been demonstrated to be feasible in large areas where salinity is already a serious problem. Overall, it can be concluded that soils in the northern part of Shaanxi province, especially after beginning irrigation, show a significant salinity increase due to rise of groundwater level (range about 50–200 cm), particularly in Mizhi and Jiaxian county in southeast part of the study area. To bring the salinity accumulation to an acceptable level, the excess water needs to be removed from the system by the selection of a proper drainage method and by applying water more efficiently using a proper irrigation method, and salinity level also needs to be monitored at certain intervals for sustainable agriculture in the area.

3.2 Vegetation change assessment

Two images taken in 1987 and 1999 showing the...
decrease in vegetation cover were used to study vegetation change in the location study (Figure 3). As shown, there was a serious decrease in the vegetation cover during the twelve-year period. The comparison between the two images showed the variation in the vegetation decreased over the past 12 years. This is shown more clearly in Table 4. During this 12-year period, however, it was clear that the farmland had decreased in the study area. The farmland areas in 1999 were less than those in 1987. Meanwhile, in Jingbian, Hengshan, Yuyang, Shenmu and Fugu the decline in vegetation coverage was conspicuous in 1999. Table 4 shows that the total vegetation area in the study location declined in both 1987 and 1999 by 23,833 km². Such a remarkable decline in vegetation was exceptional.

For the vegetation change assessment, the main indicator was considered to be the percentage of vegetation cover. The decrease of vegetation cover percentage was strongly related to the NDVI. Utilizing Eq.(4) for the two periods of 1987 and 1999, decreases in percentage of vegetation cover images were calculated and combined to produce an overlapping vegetation change map. Table 4 suggests that large-scale vegetation cover change had occurred in this area, during the 12 years of this study. However, the vegetation area had decreased as a result of soil salinization. In fact, many canals and water reservoirs were found in the images in 1999, but not in 1987. Accordingly, this could be a possible reason for the decrease in area of barren soil, although there was no available data to support this. Even though there was declining vegetation found in Shenmu and Fugu, the results in Table 4 exhibited indications of vegetation change in cover. On the other hand, decreases in vegetation for location study areas were found, indicating evidence of poor land management. This result revealed potentially high-risk land degradation areas for further investigation. Results also suggested that enhancements to this method could help monitor the condition and extent of
salinization cover areas on the margins of vegetation areas. In Table 4, the general estimation for vegetation cover change in the study location is detailed. The entire area was presumed to be subject to vegetation change, mainly by anthropogenic activities and climatic variation. Thus, 11.3% of the land area had vegetation cover in 1999, while 17.8% had vegetation cover in 1987, revealing the gravity of vegetation cover change problem in this study area.

### Table 4 Percentage of vegetation covers areas for each county in 1999 compared with 1987 in the study location

| County   | Class | TM 1987 | ETM 1999 | Total E (A/E)×100 | (A/B)×100 | (C/D)×100 | (C/A)×100 | (D/B)×100 | (A/E)×100 | (C/E)×100 |
|----------|-------|---------|-----------|--------------------|-----------|-----------|-----------|-----------|-----------|-----------|
|          | A     | B       | C         | D                  | 1987      | 1999      | 1987      | 1999      | 1987      | 1999      |
| Jingbian | 1065  | 3 975   | 878       | 4 162              | 5 040     | 26.7      | 21.1      | 82.4      | 104.7     | 21.2      | 17.4      |
| Hengshan | 895   | 3 342   | 815       | 3 422              | 4 237     | 26.7      | 23.8      | 91.1      | 102.3     | 21.1      | 19.2      |
| Mi zhi   | 220   | 622.7   | 195       | 647.7              | 842.7     | 35.3      | 30.1      | 88.6      | 104.0     | 26.1      | 23.1      |
| Yuyang   | 1 253 | 4 563   | 1 059     | 4 757              | 5 816     | 27.5      | 22.3      | 84.5      | 104.2     | 21.5      | 18.2      |
| Jiaxian  | 153   | 970     | 114       | 1 009              | 1 123     | 15.8      | 11.3      | 74.5      | 104.0     | 13.6      | 10.1      |
| Shenmu   | 1 279 | 6 185   | 565       | 6 899              | 7 464     | 20.6      | 16.0      | 82.8      | 107.3     | 19.1      | 13.9      |
| Fugu     | 440   | 2736    | 240       | 2 936              | 3 176     | 16.0      | 16.3      | 72.8      | 106.4     |           |           |
| Total    | 5 305 | 22 393  | 3 866     | 23 833             | 27 702    | 23.6      | 16.3      | 72.8      | 106.4     |           |           |

a) Vegetation covered areas; b) Non vegetation areas; c) A and C = Vegetation covered areas for 1987 and 1999, respectively; B and D = Non vegetation areas for 1987 and 1999, respectively; d) E = Total km² of vegetation cover and non vegetation areas by year.

### 3.3 Evaluation of land degradation by salinization

The land degradation areas in 1999 are larger than those in 1987: Shenmu (32.0 km²/yr), Mizhi (12.1 km²/yr), Fugu (11.2 km²/yr) area is more than Jingbian (7.3 km²/yr), Yuyang (7.8 km²/yr) and Jiaxian (3.2 km²/yr). The declining vegetation is conspicuous in 1999 and larger than that in 1987 in the Shenmu, Mizhi, and Fugu areas. However, extended land degradation was clearly found in the study location (Table 5). The arid environment of the study area is characterized by low precipitation and high evapotranspiration. Human activities, however, increased salinization by excessive application of irrigation water without adequate drainage facilities. The soil in the transitional zone (soil type clay loam and silty loam) is subjected to high to very high values. This is attributed to the existence of clay subsoil layer. According to information analysis, precipitation in the area has been reduced in the last two decades. Temperatures in other parts of the affected regions are increasing, and consequently, the evaporation potential is accelerating and the formation of soil salinization is deteriorating by the above mentioned trends. Agriculture expansion would be very risky in these surrounding areas because the coarse soil texture in this area reduces the risk of salinization.

In Table 6, we calculated areas affected by various levels of salinity in the northern part of Shaanxi Province. It is supposed that the whole area is subject to

### Table 5 Soil salinization coverage percentages and their increasing rates in the study area during the period from 1987 to 1999

| County   | County Area / km² | Soil salinization area / km² | Increase Area / km² | Percent | Land degradation Rate / (km²·yr⁻¹) |
|----------|-------------------|-----------------------------|---------------------|---------|----------------------------------|
| Jingbian | 5 040.6           | 510.9                       | 599.2               | 88.3 a) | 1.7 b)                           |
| Hengshan | 4 237.1           | 422.7                       | 532.8               | 110.1   | 2.5                              |
| Mizhi    | 842.7             | 55.2                        | 199.6               | 144.4   | 17.1                             |
| Yuyang   | 5 816.7           | 625.5                       | 719.5               | 94.0    | 1.6                              |
| Jiaxian  | 1 123.6           | 198.6                       | 237.9               | 39.3    | 3.4                              |
| Shenmu   | 7 464.7           | 572.4                       | 957.3               | 384.9   | 5.1                              |
| Fugu     | 3 176.6           | 245.2                       | 379.6               | 134.4   | 4.2                              |
| Total    | 27 702            | 2 630.5                     | 3 625.9             | 995.4   | 3.5                              |

a) Soil salinization area (km²) (1999) - Soil salinization area (km²) (1987); b) Increase area (km²) / County area (km²) × 100; c) Increase area (km²) / 12 years.
land degradation, as we mentioned previously, mainly by anthropogenic activities and climatic variation. The overall results were 72.1, 13.3, 10.1, and 4.4% for none, slight, moderate, and high land degradation by salinization risk class, respectively. When salinity changes are compared as percentages between 1987 and 1999, Table 6 indicates very clear and significant results to show the increase of the percentage of saline soils and the decrease in non-saline soils. While the non-saline soils were about 88% in 1987, the percentage decreased to about 72% in 1999. Levels of the saline soils from slight to strong also showed significant increase during these years. Specifically, strongly saline soils increased from 1% to 8% and the increase was about 6% for slightly saline soils in 12 years. Clearly, these results show the indication of land degradation by salinization in the northern part of Shaanxi province.

| Class                          | Land degradation by salinization | Area / km² | Proportion / % |
|-------------------------------|---------------------------------|------------|---------------|
| Unaffected land degradation by salinization | 19 973.1 | 72.1 |
| Slight land degradation by salinization | 3 684.7  | 13.3 |
| Moderate land degradation by salinization | 2 797.9  | 10.1 |
| High land degradation by salinization | 1 218.9  | 4.4  |
| Total land area                 | 27 702  | 100.0 |

4 Conclusions

Soil salinization indices show that most salinity problems were located along drainage canals. The salinization situation is quite alarming when comparing the change of salinization indices over a 12-year period. Evidence shows that the existing drainage system, along with the use of groundwater for irrigation, increases the extent of soil salinization. However, the reuse of poor quality water to supplement irrigation supplied by the downstream farmers and the failure of a few drainage sumps are likely to disturb the water balance resulting in an increased risk of salinity in the area. The vegetation growth analyzed through NDVI tends to be lower along the drainage and higher along the irrigation canals due to the unequal water distribution and locational disadvantage of the drains, and vice versa. High NDVI values for almost all of the study area with demand oriented water supply thus gives the solution to resolve the remaining salinity problem. Lastly, it is concluded that the water shortage is one of the fundamental problems in the area in reclaiming the soil for sustainable, productive soils.

References

[1] UNCOD (1977) Plan of action to stop desertification. Report of the UN conference on desertification [R]. A/CONF 74/36, Nairobi
[2] Reynolds J F (2001) Desertification[M]/Encyclopedia of Biodiversity. San Diego: Academic Press
[3] Wessels K J, Prince S D, Frost P E, Van Zyl D (2004) Assessing the effects of human-induced land degradation in the former homelands of northern South Africa with a 1 km AVHRR NDVI time-series[J]. Remote Sensing of Environment, 5(9): 47-67
[4] Prince S D (2002) Spatial and temporal scales of measurement of desertification[D]/ Stafford-Smith M, Reynolds J F. Global Desertification: Do Humans Create Deserts? [M]. Berlin: Dahlem University Press
[5] Hein L, De Ridder N (2006) Desertification in the Sahelian a reinterpretation [J]. Global Change Biology, 2(12): 1-8
[6] Diouf A, Lambin E (2001) Monitoring land-cover changes in semiarid regions: remote sensing data and field observations in the Ferlo, Senegal [J]. Journal of Arid Environments, 6(48): 129-148
[7] Nicholson S E, Tucker C J, Ba M B (1998) Desertification, drought, and surface vegetation: an example from the West African Sahel[J]. Bulletin of the American Meteorological Society, 4(79): 1-15
[8] Prince S D, Brown de Colstoun, E, Kravitz L (1998) Evidence from rain use efficiencies does not support extensive Sahelian desertification [J]. Global Change Biology, 3(4): 359-374
[9] Pickup G, Bastin G N, Chewings V H (1998) Identifying
trends in land degradation in non-equilibrium rangelands [J]. *Journal of Applied Ecology*, 9(35): 365-377

[10] Bastin G N, Pickup G, Pearce G (1995) Utility of AVHRR data for land degradation assessment: a case study [J]. *International Journal of Remote Sensing*, 7(16): 651-672

[11] Wu Wei (1997) Applying remote sensing data for desertification monitoring in the Mu Us sandy land [J]. *Journal of Desert Research*, 17(4): 415-420

[12] Zhang Y, Peng B Z, Gao X, Yang H (2004) Degradation of soil properties due to erosion on sloping land in southern Jiangsu Province, China [J]. *Pedosphere*, 14(1): 17-26

[13] Wang Tao (1998) Remote sensing monitoring and assessing sandy desertification: an example from the sandy desertification region of northern China [J]. *Quaternary Sciences*, 4(2): 108-118

[14] Mehami A H (1998) The influence of depth on salinity of water table on the salt levels in the duplex red-brown Earths of the goulburn valley of victoria [J]. *Australian J of Experim Agr*, 28(5): 593-597

[15] Lesch S M, Herrero J, Rhoades J D (1998) Monitoring for temporal changes in soil salinity using electromagnetic induction techniques [J]. *Soil Sci Soc Am J*, 62(1): 232-242

[16] Liu L Y (1999) The quantity and intensity of regional aeolian sand erosion and deposition: the case of contiguous region of Shanxi-Shaanxi-Inner Mongolia [J]. *Acta Geograph Sinica*, 54(1): 59-68

[17] Dejong S M (1994) Derivation of vegetative variables from a Landsat TM image for modeling soil-erosion [J]. *Earth Surface Processes and Landforms*, 19(2): 165-178

[18] Tripathi N K, Rai B K, Dwivedi P (1997) Spatial modeling of soil alkalinity in GIS environment using IRS data [C]. 18th Asian Conference on Remote Sensing, Kuala-lampur

[19] Srivastava A, Tripathi N K, Gokhale K V (1997) Mapping groundwater salinity using IRS-1B LISS II data and GIS techniques [J]. *Int J Remote Sensing*, 18(13): 2853-2862

[20] Tucker C J (1979) Red and photographic infrared linear combinations for monitoring vegetation [J]. *Remote Sensing of the Environment*, 8(2): 127-150

[21] Porevdorj T (1998) The estimation of percent green vegetation covers using AVHRR data-application to Mongolian grassland [D]. Mongolian: Chiba University