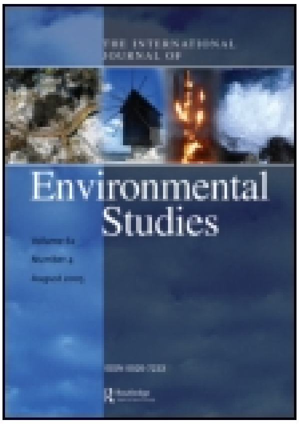

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Analysis of vegetation indices for monitoring vegetation degradation in semi-arid and arid areas of Mongolia

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An attempt has been made in this study to delineate the characteristics of spectral signatures of the vegetation in terms of various vegetation indices (VIs), particularly the Normalized Difference Vegetation Index (NDVI), Modified Soil Adjusted Vegetation Index2 (MSAVI2) and Enhanced Vegetation Index (EVI) to manifest their ability to estimate vegetation biomass over a large area and to monitor vegetation degradation in arid and semi-arid area of Mongolia. Multi-temporal SPOT-4 VEGETATION data from 1998 to 2001 have been used for the analysis. The correlations between the vegetation indices observed at various degrees of vegetation coverage during different stages of growth were examined. The results showed that in Mongolian desert steppe and Gobi desert zone MSAVI2 is the best, while in mountain steppe zone EVI is found to estimate biomass well. Generally, it was found that total biomass was decreased by 50.7% and 31.4% of rangeland is very severe degraded in the case study area.

Keywords: Vegetation indices; Vegetation dynamic; Mongolia

1. Introduction

Land degradation, which is one of representative deteriorating factors of the environment, can be observed worldwide. Degradation implies the reduction of resource potential by one or a combination of processes acting on the land. Desertification has been defined by the United Nations Environment Programme (UNEP) as land degradation in arid semi-arid and dry sub-humid areas resulting mainly from adverse human impact. The quantification of spatial behaviour at the specific moment is an initial step to monitor the progress of desertification. The capability of wide spatial coverage of remote sensing data is its advantageous feature, and remote sensing data has been evaluated as useful information to monitor land degradation [1].

Degradation of vegetation is considered to be the main form of desertification [2] and, usually regarded as a reduction in biomass and decline in the vegetative ground cover. Therefore, accurate biomass estimation is necessary for a better understanding vegetation degradation.

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In this article, for the vegetation degradation monitoring the reduction of biomass is considered. In order to explore estimation biomass using remote sensing data various vegetation indices were tested in the different natural zones.

2. Study area

Our experiment for testing the ability of VIs to estimate vegetation biomass at various degrees of vegetation coverage during different stages of growth was conducted in grassland area of Mongolia, which is geographically located between 41°35′N to 52°09′N and 87°44′E to 123°00′E. Total area is 1.565000 km^2. The territory of Mongolia is divided into several natural zones such as mountain, mountain steppe, plain steppe, desert steppe and the Gobi desert. Mountain steppe, plain steppe and desert steppe are most significant and are large for livestock and agriculture. The climate of country is characterized by short, dry summer and long cold winter season. The mean annual precipitation is 200–300 mm. The growing season runs from end of May to the end of August. The significantly dry climate, low soil fertility and sparse vegetation cover of country, with over 40% of it's territory included in the geographic area of the desert steppe and Gobi desert, make desertification a key issue of environmental concern. It has been estimated that over 78% of the total territory of Mongolia is under risk of desertification, of which nearly 60% is classed as highly vulnerable. Over 70% of the total pastures have been degraded through overgrazing as well as drought and problems of environmental deterioration are further exacerbated by the ploughing of over 1.3 million hectare of land for arable agriculture, much of which is now seriously depleted in fertility and abandoned. For monitoring vegetation degradation 349772 km^2 area of desert steppe and Gobi desert area (41°35′N to 46°48′N and 99°25′E to 111°58′E) is considered as a case study area (figure 1).

3. Data

3.1. Multi-temporal SPOT-4 VGT sensor data

In this article, we acquired VGT-S10 data from 1 April 1998 to 30 September 2001 (a time series of observations). The VGT sensor belongs to a new generation of space-borne optical sensors that were designed for mainly observations of vegetation and land surfaces [3].

Figure 1. The study area: Mongolia.

3.2. Ground truth data

The biomass measurement is carried out by cutting all the grass inside an area of $1m^2$ by hand. In this article 160 biomass measurement data sampled from 15 sites were used. Biomass measurement data is carried out based on 10-day interval from middle of June 1998 to middle of September 2001. The 15 sites were selected from different natural zones as follows:

- Two sites are located in mountain steppe, which is widespread in central, north and western regions of Mongolia and usually has dark brown and brown soil. Common grasses in this area are *F. lenensis, F. sibirica, Polygonum angustifolium, Coluria geodes, Crossularia acicularis* and *Pentaphylloides fruticosa*.
- Eight sites are located in plain steppe, which is abundant between the small mountain and valleys. The prevailing herbs and plants in this area are *Stipa capillata, S. decipiens, S. grandis and Cleistogenes squarros*.
- Five sites are located in desert steppe and Gobi desert, which is located in the southern section of Mongolia. Soil is grey-brown and desert steppe brown with pebbles. Plants abundant in this area are *Stipa gobica, S. glareosa, Cleistogenes squarrosa, S. klemenzii* and *C. songorica*, and less abundant plants are *Kochio prostrate, Allium polyrrhizum* and *A. mongolicum*.

4. Methodology

4.1. Vegetation indices

NDVI, MSAVI2 and EVI were calculated for each of the VGT-S10 products. NDVI is a normalized ratio of the NIR and red bands:

$$NDVI = \frac{NIR - \mathrm{Re}\,d}{NIR + \mathrm{Re}\,d} \tag{1}$$

Huete [4] suggested a new vegetation index which was designed to minimize the effect of the soil background, which he called the soil-adjusted vegetation index (SAVI). An iterated version of modification of this vegetation index which is called MSAVI2 [5]:

$$MSAVI2 = \frac{2NIR + 1 - \sqrt{(2NIR+1)^2 - 8(NIR - \mathrm{Re}\,d)}}{2} \tag{2}$$

EVI was developed to optimize the vegetation signal with improved sensitivity for high biomass regions and improved monitoring through de-coupling of the canopy background signal and reduction in atmospheric influences:

$$EVI = G\frac{NIR - \mathrm{Re}\,d}{NIR + C_1\,\mathrm{Re}\,d - C_2 Blue + L} \tag{3}$$

where L is the canopy background adjustment that addresses non-linear, differential NIR and Red radian transfer through a canopy, and C1, C2 are the coefficients of the aerosol resistance term, which uses the blue band to correct the aerosol influences of the red band.

The coefficients adopted in the EVI algorithm are, L = 1, C1 = 6, C2 = 7.5, and G (gain factor) = 2.5 [6].

4.2. Analysis

Relationships between vegetation indices observed at various degrees of vegetation coverage during their different stages of growth were analysed and the relationships between VIs and biomass were investigated using ground measurement data. The accuracy of the estimate biomass by vegetation index was measured using a standard error of estimate. The standard error is calculated by following equation:

$$SE = \sqrt{\frac{1}{N-2}\sum_{i=1}^{N}(\hat{y}_i - y_t)^2} \tag{4}$$

where $\hat{y}_i$ and y_i are the predicted and ground measured value, of biomass respectively, and N the number of samples.

Sensitivity analysis consists of computing derivatives of one or more quantities (outputs) with respect to one or several independent variables (inputs). The sensitivity of vegetation indices to vegetation density was evaluated using finite-differences method. Finite-differences method for sensitivity analysis is calculated by following equation:

$$\frac{df}{dx_i} \approx \frac{f(x_i + h) - f(x_i)}{h} + O(h) \tag{5}$$

where h is the finite-difference interval, the truncation error is O(h), and hence this is a first-order approximation and $f(x_i + h)$, $f(x_i)$ is the value of function at x_i and $x_i + h$ points.

In order to designate the severity of degradation the terms slight, moderate, severe and very severe is used. Slight, moderate, severe and very severe vegetation degradation reflect less than 25% loss in productivity, 25–50% loss, 50–75% loss, and greater than 75% loss, respectively [7].

5. Results

Vegetation indices were calculated from SPOT-4 Vegetation data of April to September from 1998 to 2001, and the relationship between vegetation indices for each 10 day series were investigated. In early stages of growing season EVI is less correlated to the NDVI and MSAVI2. Apparently, the NDVI and MSAVI2 are highly correlated for all of the temporal changes and in different natural zones. Correlation coefficients between vegetation indices for study area are shown in the table 1. The relationships between biomass and each vegetation index for each natural zone are shown in figures 2–4.

In the mountain steppe zone EVI and biomass are correlated better than the other indices. The biomass and EVI are exponentially related; as vegetation index increases, biomass becomes saturated. MSAVI2 and biomass are correlated well in desert steppe zone Gobi desert. Table 2 shows the correlation functions and coefficients between biomass and vegetation

Table 1. Correlation coefficients between vegetation indices for the study area.

	EVI & MSAVI2	*EVI & NDVI*	*MSAVI2 &NDVI*
April	0.55	0.58	0.98
May	0.88	0.91	0.98
June	0.96	0.91	0.98
July	0.96	0.98	0.99
August	0.94	0.97	0.98
September	0.91	0.96	0.98

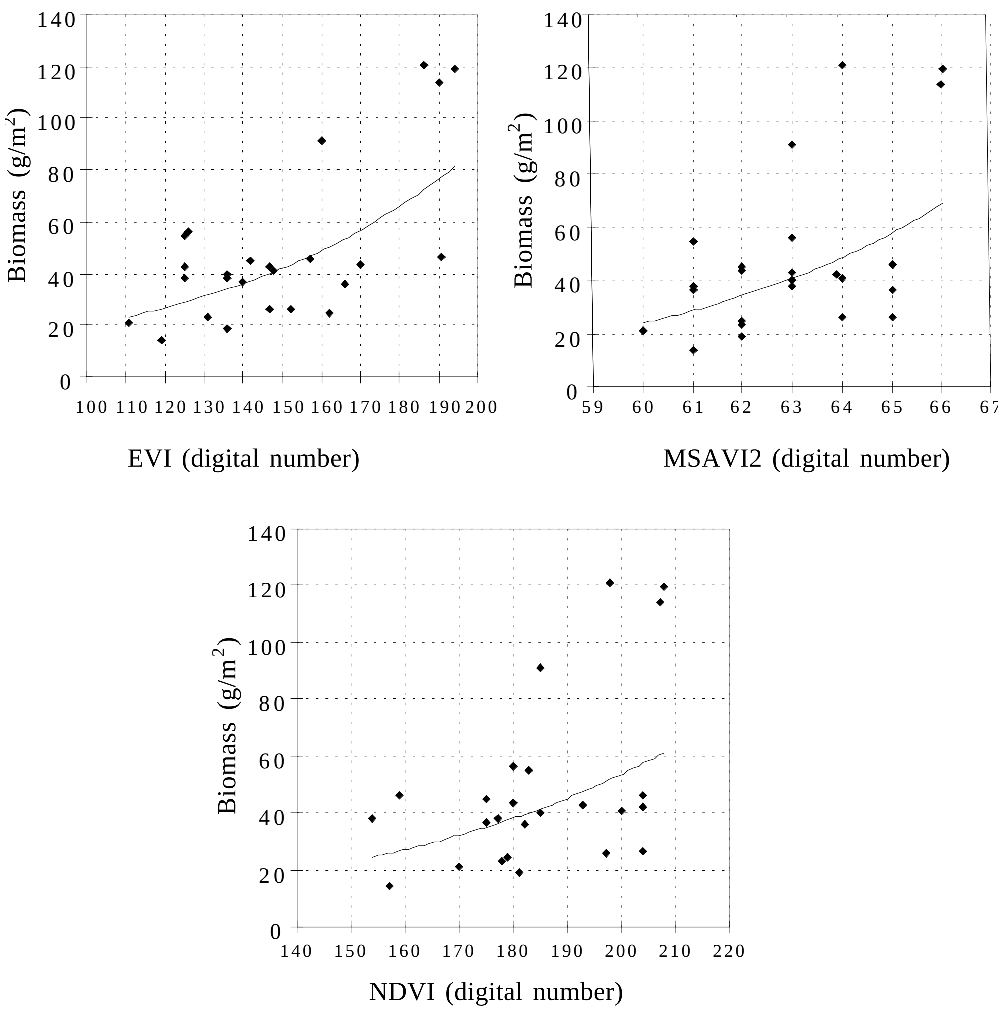


Figure 2. The relation between biomass (g/m^2) and vegetation indices in the mountain steppe zone.

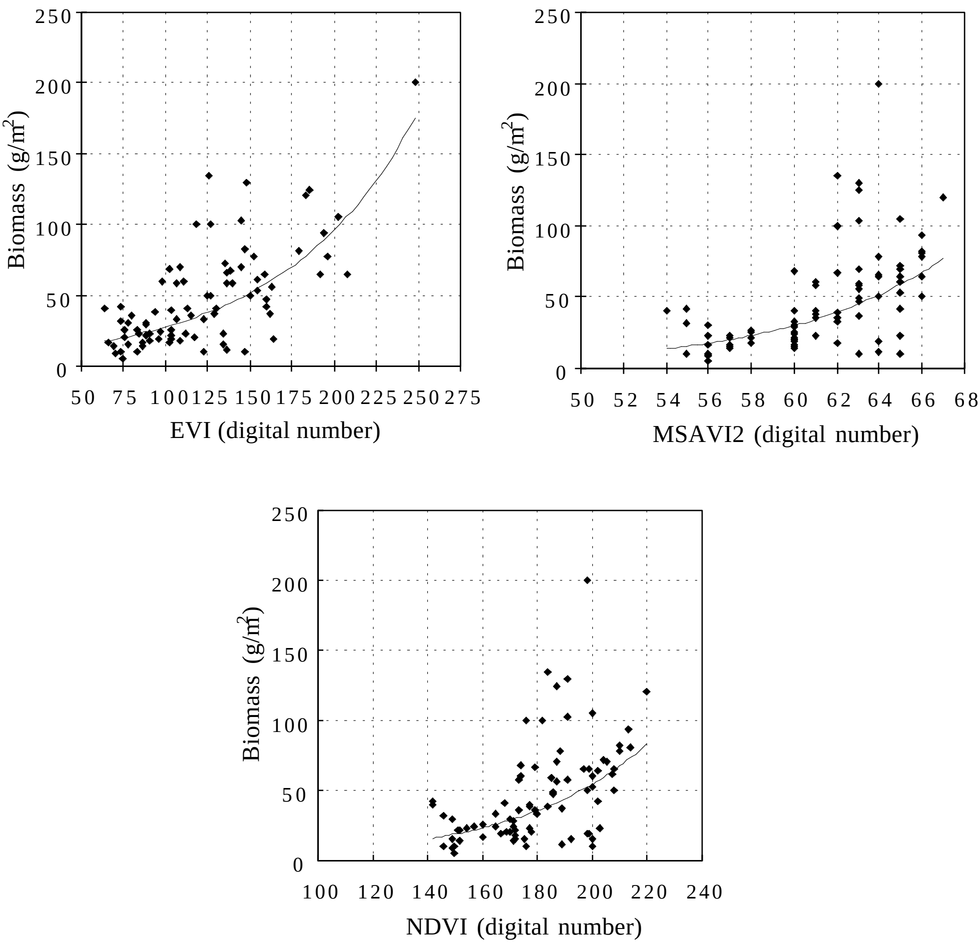


Figure 3. The relation between biomass (g/m^2) and vegetation indices in the plain steppe zone.

indices and the standard error of estimate for biomass from different vegetation indices for each natural zone.

In this article sensitivity of vegetation indices to vegetation density is evaluated in different zones separately. The sensitivity results are shown in figure 5. In desert steppe and Gobi desert zone MSAVI2 is more sensitive to the vegetation density. In plain steppe zone sensitivities of the vegetation indices are similar. In mountain steppe EVI is more sensitive to vegetation density.

The standard error of estimate of biomass from MSAVI2 was lower in desert steppe and Gobi desert area and it employed to calculate biomass in the case study area. Figure 6 shows the biomass amount of the case study area from August of 1998 to 2001. It was found that the amount of biomass decreased by 50.7% during the period 1998–2001 and annual mean decreasing percentage is 19.8%. After calculation of biomass, the severity of degradation is designated and the size of land in each desertification class was estimated. The result show that 154899 km^2 area of case study area is very severe degraded during the

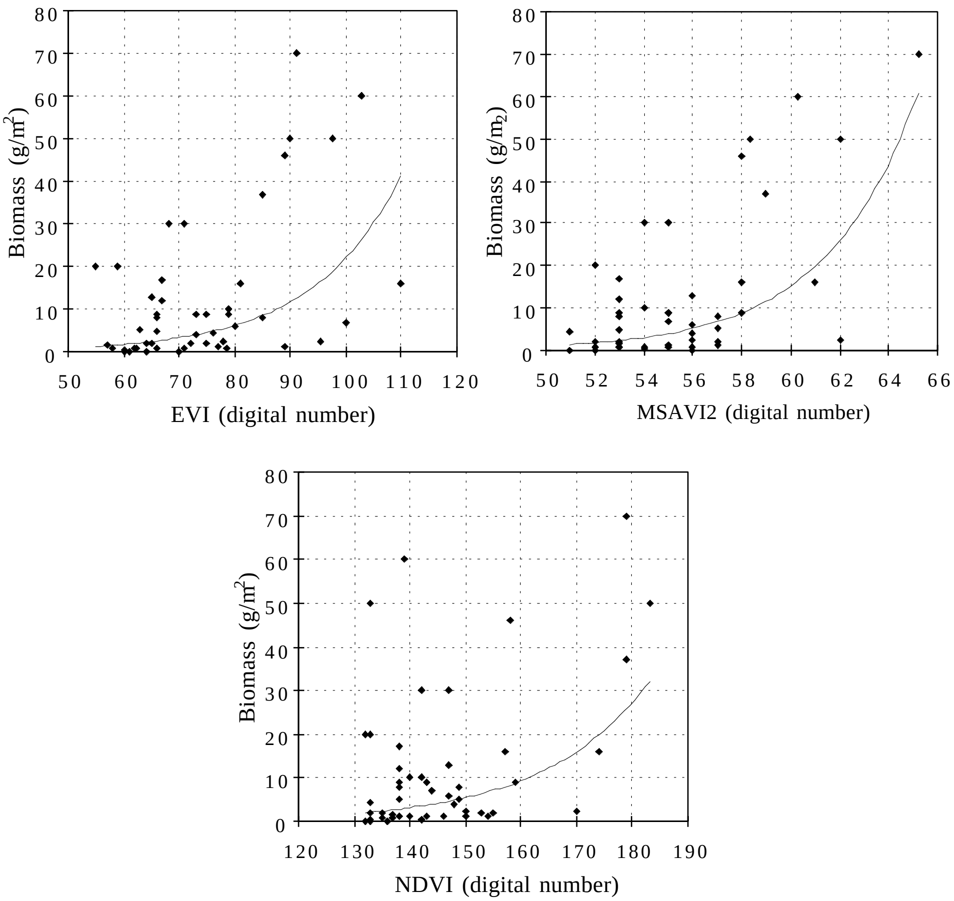


Figure 4. The relation between biomass (g/m^2) and vegetation indices in the desert steppe and Gobi desert zone.

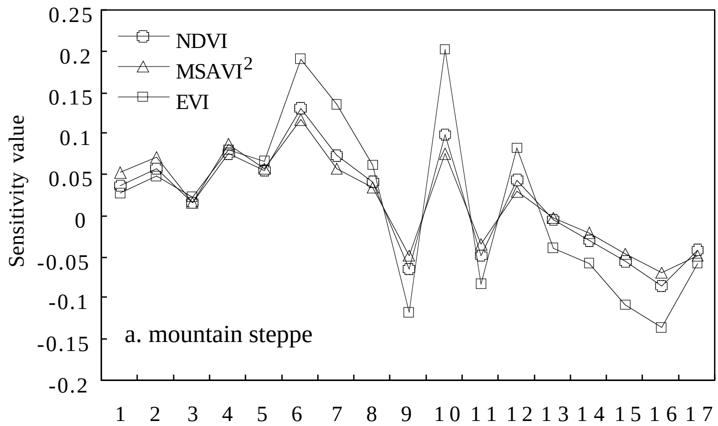
1998 and 2001. Detailed information about amount of land in each desertification class as represented in table 3. The map of vegetation degradation of the case study area is shown in figure 7.

6. Conclusion

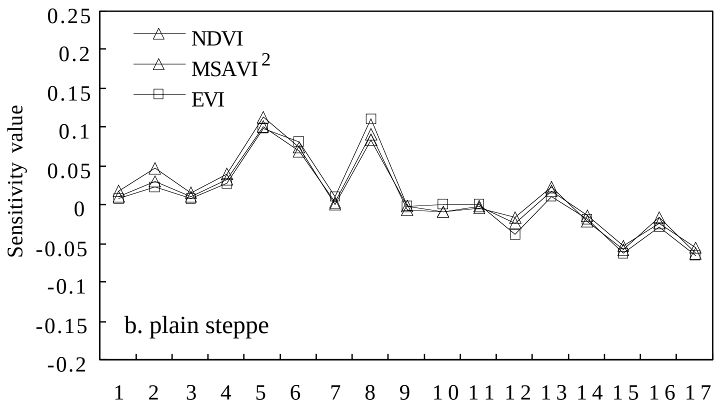
The main objective of this article was to monitor vegetation degradation in semi-arid and arid area of Mongolia. In order to monitor vegetation degradation, different VIs were tested based on the spectral signatures of the vegetation types, to estimate the vegetation biomass. The article has demonstrated, in general, that satellite remote sensing data has considerable scope as a tool for monitoring vegetation degradation and also it has presented that the amount of biomass in some area of semi arid and arid area of country decreased highly during the period 1998–2001. It should be noted that in this article, a period of four years is considered and further study is necessary to observe biomass changes for a longer term.

Table 2. Correlation functions and coefficients between each vegetation index and biomass (m_b) and standard errors of estimates of biomass for various vegetation indices in different natural zones.

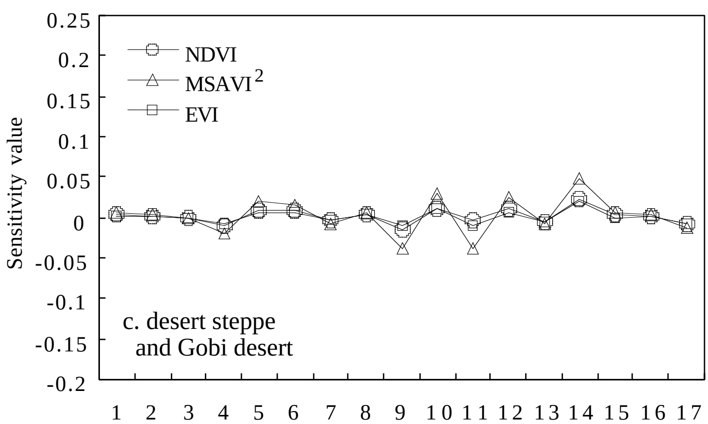
	EVI			MSAVI2			NDVI		
Natural zones	*Function*	r	*STE*	*Function*	r	*STE*	*Function*	r	*STE*
Mountain steppe	$m_b = 4.4088e^{0.015\,EVI}$	0.64	7.64	$m_b = 0.0007e^{0.1752\,MSAVI2}$	0.53	11.70	$m_b = 1.7528e^{0.0171\,NDVI}$	0.53	14.47
Plain steppe	$m_b = 7.7796e^{0.0126\,EVI}$	0.65	17.56	$m_b = 0.0091e^{0.1350\,MSAVI2}$	0.50	5.47	$m_b = 0.7714e^{0.0213\,NDVI}$	0.56	13.57
Desert steppe and Gobi desert	$m_b = 0.1407e^{0.047\,EVI}$	0.48	6.68	$m_b = 2\mathrm{E}-06e^{0.2682\,MSAVI2}$	0.59	3.45	$m_b = 0.0017e^{0.0537\,NDVI}$	0.41	9.48



(a) Finite-difference interval (10-day interval from April to September



(b) Finite-difference interval (10-day interval from April to September



(c) Finite-difference interval (10-day interval from April to September

Figure 5. Sensitivity analysis of VIs at 10-day interval over the period of April–September in different natural zones: (a) mountain steppe; (b) plain steppe; (c) desert steppe and Gobi desert zone.

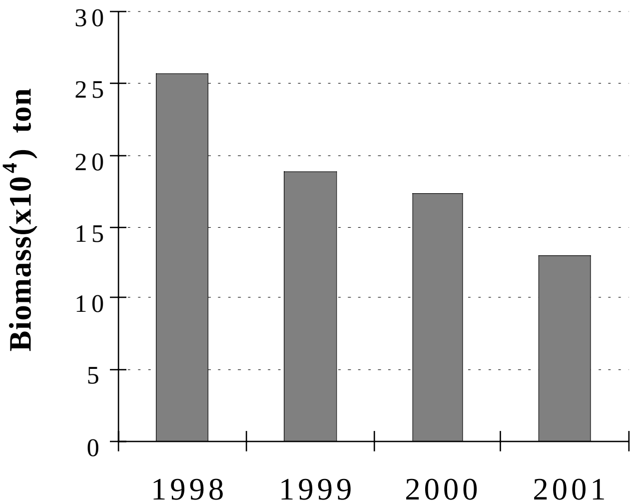


Figure 6. The biomass amount of the case study area (349773 km^2) from 1998 to 2001.

Table 3. Percentages of land in each desertification class.

Total land area (km^2)	*Very severe*		*Severe*		*Moderate*		*Slight*		*Non-effected*	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
349772	154899	31.4%	106531	21.6%	182119	36.9%	18378	3.7%	31811	6.4%

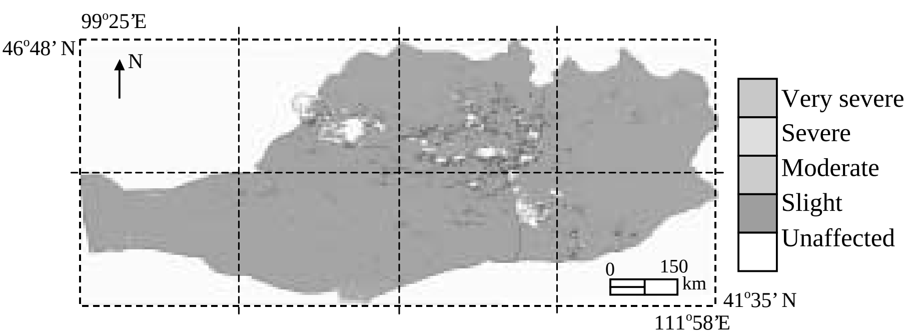


Figure 7. Vegetation degradation map of the case study area.

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