*Wuyunna et al., International Journal of Ecodynamics. Vol. 2, No. 2 (2007) 97–107*

# ANALYSIS OF VEGETATIVE BIOMASS CHANGES IN STEPPES OF INNER MONGOLIA, CHINA, USING MULTITEMPORAL LANDSAT, CLIMATIC, AND SOCIOECONOMIC DATA

WUYUNNA[1], K. OKAMOTO[2] & H. KAWASHIMA[3]
[1]College of Life Science, Dalian Nationalities University, China.
[2]National Institute for Agro-Environmental Sciences, Japan.
[3]Graduate School of Agricultural and Life Sciences, University of Tokyo, Japan.

ABSTRACT

Land use and land cover changes are important aspects of global environmental changes. They are controlled by natural factors and are affected by socioeconomic, technological, and historical factors. In this study, multitemporal Landsat images were used to analyze changes in biomass. We aimed at obtaining information for better decision-making regarding land use in the semiarid areas of Inner Mongolia. Information on land use and land cover in the steppes of Inner Mongolia, China was derived from multitemporal Landsat Thematic Mapper (TM) images in 1989, 1994, and 1997, and a Landsat Enhanced Thematic Mapper Plus (ETM+) image in 2002. On the basis of the vegetation index, five vegetative biomass zones were delineated from the TM/ETM+ images: no vegetation, low biomass, middle biomass, high biomass, and woods. Changes in vegetative biomass were analyzed, in relation to natural factors, such as monthly mean temperature and precipitation. The results suggest that a change in vegetative biomass depends on that in meteorology. Changes in vegetative biomass were also analyzed, in relation to socioeconomic factors, such as overgrazing, population increases, and agricultural production. With increasing population pressure, proper land use is important for a sustained yield and the conservation of a semiarid ecosystem.
*Keywords: biomass, desertification, Inner Mongolia semiarid regions, land under cultivation, remote sensing.*

## 1 INTRODUCTION

Studies of land cover and landscapes from the air date back to the 1920s [1]. The arrival of earth observation satellites and the rapid development of computer technology have made the detailed mapping of land cover in large areas possible [2, 3]. Since the 1980s, satellite remote sensing has played an important role in the research on global changes, natural resources, and socioeconomic development on both global and regional scales [4–6]. Land use is a driving force for changes in land cover. Human activity is reflected in land use and land cover changes [7]. Therefore, research on land use and land cover changes can improve the understanding of global changes and the interactions among land ecosystems.

In recent years, as a result of land degradation and desertification, dust storms have occurred in northern China at an alarming rate. These dust storms threaten the socioeconomic development and ecological security in northern China, affecting neighboring countries such as Japan and Korea. This problem is monitored by the entire world with keen interest. To minimize the expansion of desertification, which was of great concern worldwide in March 2000, the Chinese Government implemented the Reforestation and Regrassing Project. To determine the extent of expansion of desertification and the results of this project, satellite remote sensing has proven very effective.

Land use and land cover changes are important aspects of global environmental changes. They are controlled by natural factors and are affected by socioeconomic, technological, and historical factors. In this study, multitemporal Landsat images were used to analyze changes in biomass. In this study, we aimed at obtaining information for better decision-making regarding sustainable agriculture and livestock farming in the semiarid areas of Inner Mongolia.


ISSN: 1743-5242 (paper format), ISSN: 1743-5250 (online), http://journals.witpress.com
DOI: 10.2495/ECO-V2-N2-97-107

## 2 STUDY AREA

The study area is located north of Hohhot, the capital city of Inner Mongolia Province, China (N 40°50′–42°45′, E 111°–113°50′), including Siziwang Qi (the administrative category 'Qi' is equivalent to a prefecture, Fig. 1). From the north to the south, the elevation of the study area changes from 1,050 to 2,100 m. The annual precipitation varies from 200 to 400 mm, and the annual mean temperature is 5.2°C. This semiarid area has a short growing period for plants and a delicate ecosystem. The agricultural economic pattern is largely a mixture of farming and stockbreeding owing to the semiarid environment and the mixed inhabitants composed of Han Chinese and Mongolian ethnic people. The major crops in the study area include rice, maze, wheat, pea, sweet potato, and rape. The major livestock includes sheep, goats, cows, and horses.

## 3 GRADING VEGETATIVE BIOMASS ON THE BASIS OF RELATIVE THICKNESS

In this study, the extent of desertification was evaluated on the basis of vegetative biomass. Vegetative biomass between bare ground and high-density vegetation was graded by a deductive method, which assumes the reflectance of bare ground and high-density vegetation to be constant to normalize interannual remote sensing data [8]. A scattered graph of land cover classes derived from a classification based on spectral characteristics has a triangular schematic shape on red and infrared spaces, as shown in Fig. 2. The classes for bare ground are plotted near the base of the triangle and form a line, which is called the soil line [9]. Classes that fall near the base of this triangle are those with sparse vegetation, whereas a class falling at the apex is one with the thickest vegetation. A soil line is drawn to pass a cluster of bare-ground classes. Woody vegetation grows thickly independent of annual rainfall patterns, whereas the growth of herbaceous plants depends on annual rainfall. In this study, the soil line is defined as the line delineating the no vegetative biomass, and a line that is parallel to the soil line and passes the apex is defined as the line delineating the thickest vegetative biomass. Parallel lines between these lines are drawn to define several grades of vegetative biomass (Fig. 2).

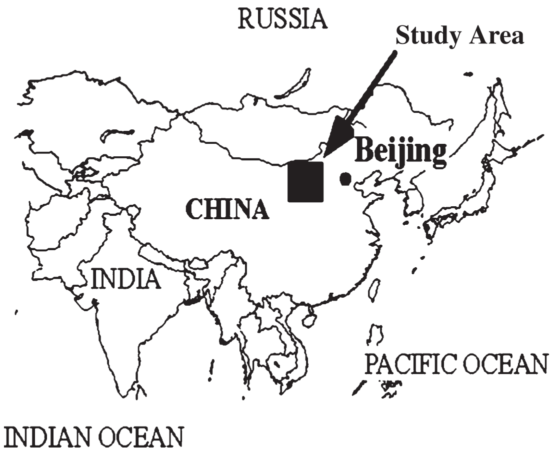


Figure 1: Study area: north of Hohhot, the capital city of Inner Mongolia Province, China (N 40°50′–42° 45′, E 111°–113°50′).

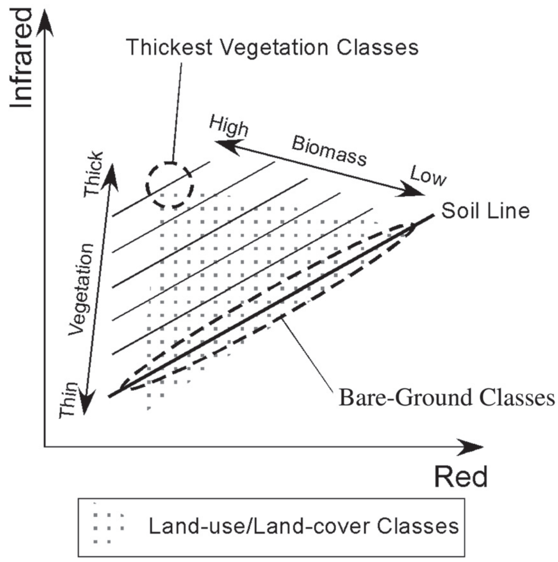


Figure 2: Schema for grading vegetative biomass on red and infrared axes.

## 4 DATA AND METHOD

### 4.1 Data

The Landsat Thematic Mapper (TM) data obtained on three different dates (3 August 1989, 1 August 1994, and 9 August 1997) and the Landsat Enhanced Thematic Mapper Plus (ETM+) data obtained on 15 August 2002 were used to classify land use/land cover. August is the time of the year when vegetation growth reaches the maximum in the study area. The spatial resolution of Landsat TM and ETM+ data is 30 m by 30 m. In addition to the TM/ETM+ data, the maps of vegetation types, grassland types, and land use were used for the study area, all on a scale of 1:1,500,000 [10]. Statistical data, which included socioeconomic data since 1949 (i.e. population count, number of livestock, and food production), and meteorological data since 1959 (i.e. monthly precipitation and monthly mean air temperature) were also used.

### 4.2 Method

The Landsat TM and ETM+ data were classified before grading vegetative biomass. The ETM+ data were geocoded using geographical information in the data header record and given geographical coordinates using the universal transverse Mercator's (UTM) projection (Zone = 49), a spheroid WGS84, and a pixel size of 30 m by 30 m. The TM data were registered to be overlaid on the ETM+ data. The data sets of bands 1 (blue), 3 (red), 4 (near infrared), 5 (middle infrared), and 7 (middle infrared) from the TM and ETM+ data were classified by the unsupervised method, ISODATA, in which 30 initial classes, a $2\sigma$ class radius, and a 98% convergence limit were used as parameters. Referring to the vegetation map, the grassland map, and the land use map [10], and making full use of both our knowledge of the local ecology and our experience with ground surveys of the study area, the land use/land cover classes were reclassified into eight classes, namely woods, thick cropland, high vegetative biomass, middle vegetative biomass, low vegetative biomass, no or slight vegetation, water, and clouds.

The soil lines for the data from 1989 to 2002 were derived from a linear regression analysis using the no or sparse vegetation class on the TM3–TM4 space, where TM3 and TM4 represent the digital number (DN) of bands 3 (red) and 4 (infrared), respectively, for the TM/ETM+ data. For 1989, 1994, 1997, and 2002, the line for the thickest vegetative biomass was defined to be parallel to the soil line and to pass the class for the thickest wood (hereinafter, called the wood line). Four parallel lines between the soil line and the wood line were derived at even intervals to define five zones for the vegetative biomass: namely a no or slight biomass zone, a low-vegetative biomass zone, a middle-vegetative biomass zone, a high-vegetative biomass zone, and a wooded zone. The extent of desertification was examined by comparing changes in vegetative biomass from 1989 to 2002.

## 5 RESULTS AND DISCUSSION

### 5.1 Trend of vegetative biomass changes on a regional scale

The classification results for remotely sensed images obtained on four different dates are shown in Fig. 3. The red areas represent no or slight vegetation zones, whereas dark green areas represent high-vegetative biomass zones. To show the transition of the steppes, particularly the changes in farmland and woodland areas, four sites, namely Siziwang Qi, Jining City, Hill 1, and Hill 2, were selected as typical areas for land cover change analysis. No or slight vegetation zones are distributed mainly in the northern part of the study area. In Siziwang Qi and its vicinity, a thick cropland zone appeared in 2002, indicating croplands with a high vegetative biomass. In Jining City and its vicinity, the areas of woodlands increased in 2002. In Hill 1, the areas of vegetative biomass zones did not

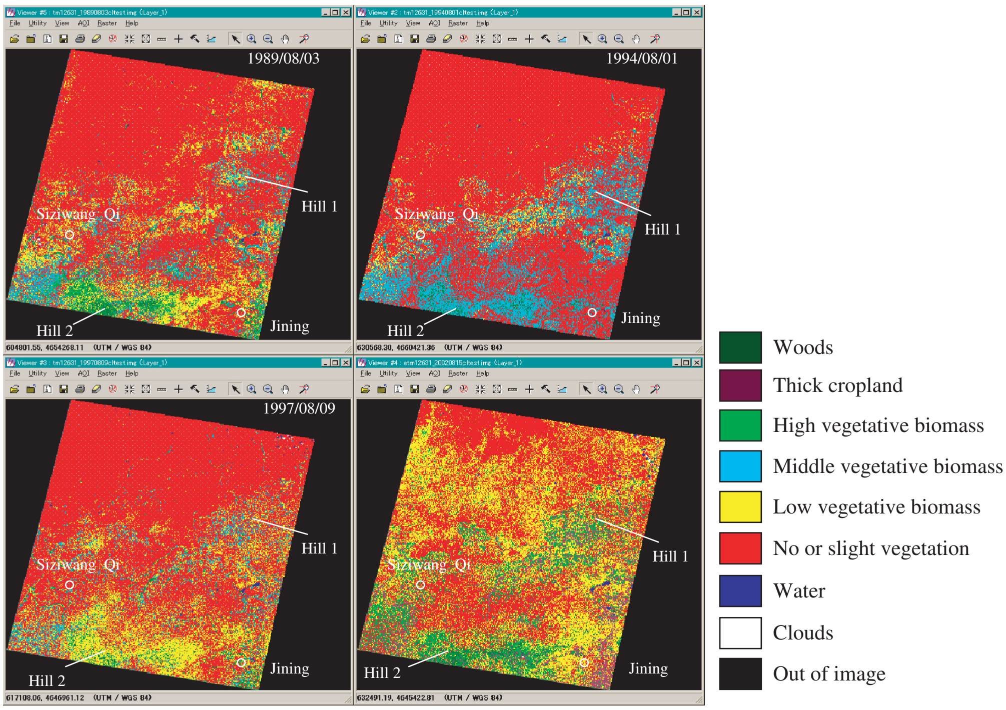


Figure 3: Land cover maps in 1989, 1994, 1997, and 2002.

change significantly in 1989, 1994, and 1997, whereas vegetative biomass increased significantly in 2002. In Hill 2, vegetative biomass decreased in 1997, whereas the area of woodlands in 1989 was the same as that in 2002.

Table 1 shows a list of areas and the percentages of vegetative biomass zones derived from landset TM/ETM+ data-based land cover maps in 1989, 1994, 1997, and 2002. Figure 4 shows the rates of change in the areas of biomass zones obtained in these periods compared with those obtained in 1989. Table 1 and Fig. 4 indicate the following:

1. The no or slight vegetation zone occupied 72% of the study area in 1989 and 1997, and 44–45% in 1994 and 2002.
2. The total areas of no or slight vegetation and low-vegetative biomass zones were 78–91% of the study area since 1989.

Table 1: Areas and percentages of vegetative biomass zones derived from Landsat TM/ETM+ data-based land cover maps in 1989, 1994, 1997, and 2002 (percentages in parentheses, unit: $km^2$, %).

| | 1989/08/03 | 1994/08/01 | 1997/08/09 | 2002/08/15 |
|---|---|---|---|---|
| Thick cropland | 0 (0.0) | 0 (0.0) | 0 (0.0) | 1,830 (6.6) |
| Woods | 399 (1.4) | 482 (1.7) | 363 (1.3) | 465 (1.7) |
| High biomass | 1,282 (4.6) | 2,028 (7.3) | 603 (2.2) | 3,593 (12.9) |
| Middle biomass | 1,992 (7.1) | 2,536 (9.1) | 1,578 (5.5) | 0 (0.0) |
| Low biomass | 4,148 (14.9) | 10,145 (36.4) | 5,056 (18.1) | 9,690 (34.7) |
| No vegetation | 19,982 (71.7) | 12,647 (45.4) | 20,187 (72.4) | 12,175 (43.7) |
| Clouds | 19 (0.1) | 0 (0.0) | 8 (0.0) | 24 (0.1) |
| Water | 66 (0.2) | 51 (0.2) | 94 (0.3) | 111 (0.4) |
| Out of image | 0 (0.0) | 0 (0.0) | 0 (0.00) | 2 (0.0) |
| Total | 27,889 | 27,889 | 27,889 | 27,889 |

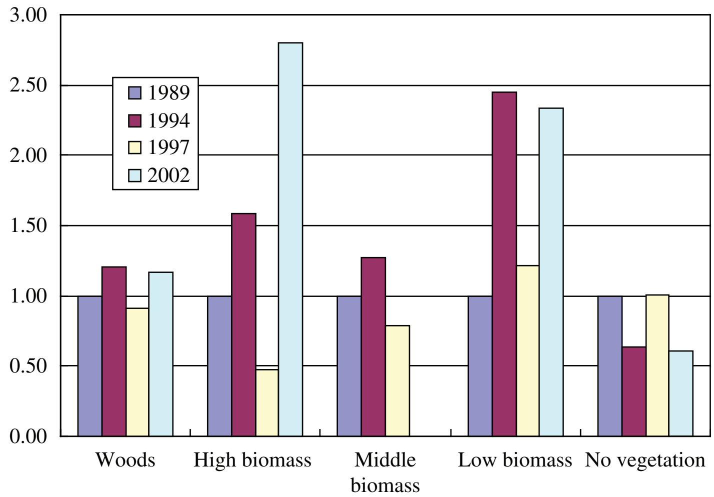


Figure 4: Rates of change in areas of biomass zones compared with 1989 values.

3. Zones of 12%, 16%, 8%, and 20% of the study area had middle vegetative biomass, high vegetative biomass, and thick cropland in 1989, 1994, 1997, and 2002, respectively.
4. Vegetative biomass was high in 1994 and 2002, whereas vegetative biomass decreased in 1989 and 1997.
5. The rate of change in the area of woodlands with respect to the total area was 1.5% for four images, increasing or decreasing by 0.2 points.

### 5.2 Socioeconomic factors for vegetative biomass changes

Overgrazing, population increases, cultivation, and climate fluctuations are the main factors considered to contribute to grassland degradation [11]. Because the study area occupies a major part of Wulanchabu Meng (the administrative category 'Meng' is equivalent to a city in other provinces), the following discussion is based on socioeconomic data for Wulanchabu Meng.

Figure 5 shows changes in the number of livestock obtained on the basis of the data collected in 1949. It can be noted that the number of livestock increased steadily from 1949 to 2002, with significant increases in the period from 1992 to 2002. Changes in the numbers of small livestock (e.g. sheep and goats) were similar to the general trend, whereas no significant changes were noted in the numbers of large livestock (e.g. cows, horses, camels, donkeys, and mules). According to interviews with local nomads, grassland grazing has been combined with stall-feeding to restore degraded grasslands. The government has also started providing assistance to the nomads; for example, hay products from Heilongjiang Province were supplied to nomads in Inner Mongolia Province in recent years to encourage stall-feeding.

Indeed, since 1994, a series of measures have been taken to protect the environment, including ecological immigration (i.e. population relocation to conserve the environment), planting of protective woods, establishment of man-made grasslands, and restoration of woods and grasslands. Some

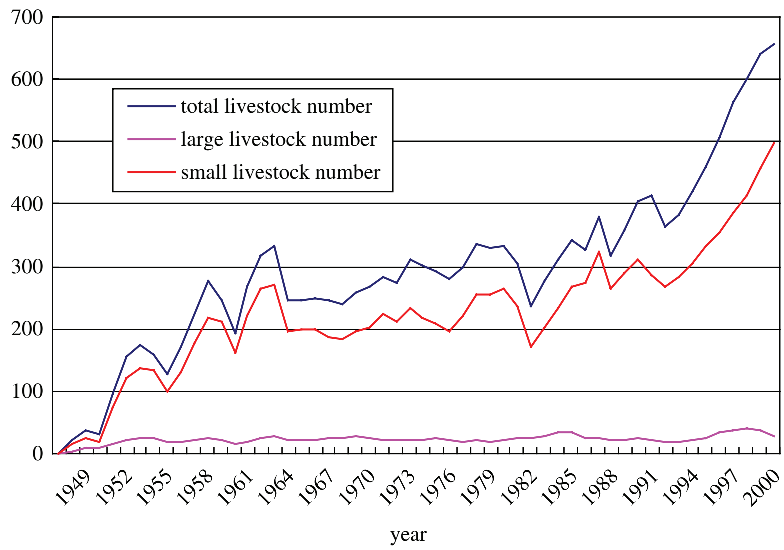


Figure 5: Changes in number of livestock in Wulanchabu Meng (difference from 1949; one unit is equivalent to 10,000 heads).

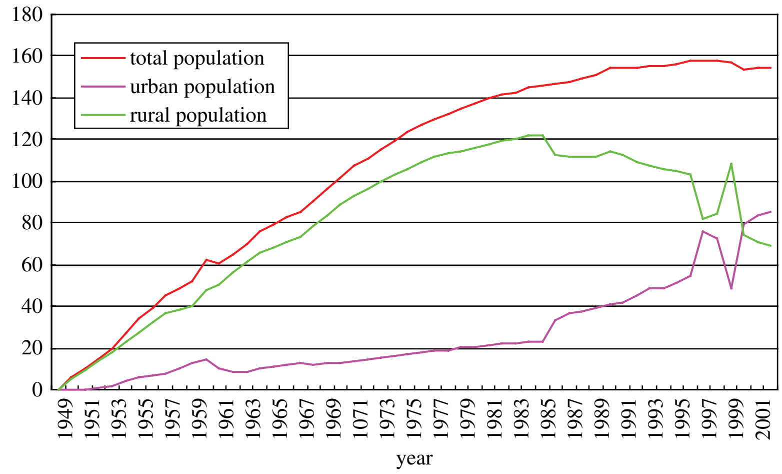


Figure 6: Population in Wulanchabu Meng (Difference from 1949 value; one unit is equivalent to 10,000 people).

of these activities can be inferred from the images obtained by remote sensing. As an example, 509 families (2,536 people) from Siziwang Qi have been relocated due to ecological deterioration. Such a relocation was called ecological immigration, and, as a result, 72.73 $km^2$ of woodlands and grasslands was restored, according to interviews. Because of the efforts of the government and livestock farmers, including practices such as graze rotation and stall-feeding, there was no obvious trend of desertification in the study area during the periods of this study.

Population has increased rapidly since 1949. In 2000, urban population exceeded rural population (Fig. 6). It is deduced that the fluctuating agricultural production since the late 1980s (Fig. 7) is responsible for the flow of population from rural areas to urban areas. It is also deduced that the Open Economy Policy since 1980 and a desire for more income triggered this population movement and that the Reforestation and Regrassing Project since 1994 accelerated this population movement (Fig. 6).

As shown in Table 2, the cultivated area of Wulanchabu Meng has decreased gradually since 1994, whereas the cultivated area of Siziwang Qi increased suddenly in 1997. A decrease in cultivated area may cause an increase in the area of grasslands. The number of livestock increased rapidly in the 1990s.

### 5.3 Natural factors for vegetative biomass changes

Meteorological data for Siziwang Qi can be used as climatic indicators for a study area with a homogeneous topography. Comparing the monthly mean precipitation value from 1959 to 2002 with those in 1989, 1994, 1997, and 2002, large variations in monthly mean precipitation, but no variations in temperature are observed (Fig. 8). The largest variation in mean precipitation is observed in July and August, and precipitation in the study area peaks from May to September. However, after mid-August, precipitation exerts a limited effect on vegetation growth because the vegetation has matured by then.

Regarding precipitation, May, June, and July were the most important months affecting the growth of steppe vegetation analyzed from the multitemporal Landsat data in this study. The precipitations for these three months in 1989, 1994, 1997, and 2002 were 96 mm, 122 mm, 109 mm, and 135 mm, respectively. The precipitations for these three months were lower than the average of 138 mm for

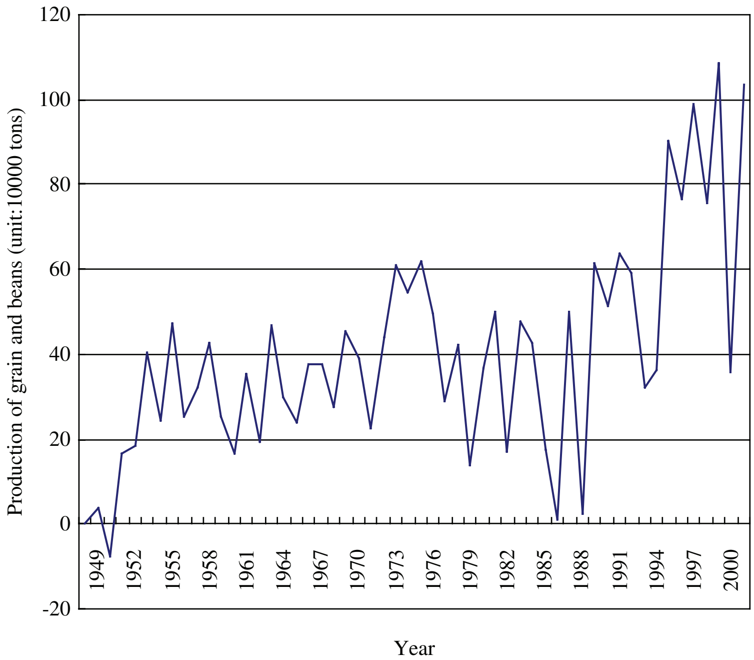


Figure 7: Crop production in Wulanchabu Meng in study area (difference from 1949 value).

Table 2: Areas of cropland in Wlanchabu Meng and Siziwang Qi (unit: $km^2$).

| Year | Siziwang Qi | Wulanchabu Meng |
|---|---|---|
| 1990 | 1,388 | – |
| 1991 | 1,377 | – |
| 1992 | 1,358 | – |
| 1993 | – | – |
| 1994 | 1,287 | 14,490 |
| 1995 | 1,074 | 13,167 |
| 1996 | 1,067 | 12,757 |
| 1997 | 1,661 | 12,337 |
| 1998 | 1,644 | 11,962 |
| 1999 | 1,580 | 11,502 |
| 2000 | 1,495 | 11,115 |
| 2001 | 1,393 | 10,644 |
| 2002 | 1,298 | 10,073 |
| 2003 | 1,205 | 9,581 |

44 years. Generally, the study area tends to experience drought. The average temperatures for these three months in 1989, 1994, 1997, and 2002 were 16.8°C, 17.6°C, 17.4°C, and 17.7°C, respectively, and they were higher than the average temperature (16.6°C) for these months from 1959 to 2002.

As shown in Fig. 9, plural relationships exist between precipitation and vegetative biomass zones. The vegetative biomass zone ‘thick cropland’ is a special zone and may replace the middle biomass

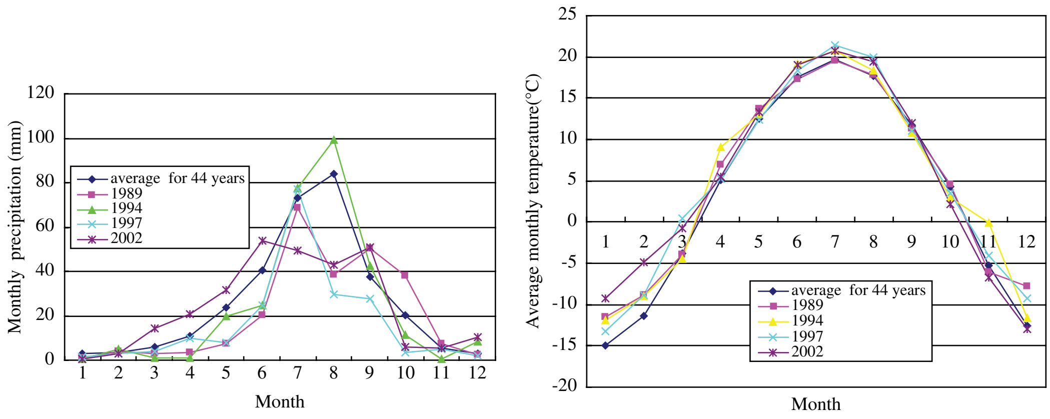


Figure 8: Comparison of monthly precipitation (left) and temperature (right) in 1989, 1994, and 1997 and average for 44 years in Siziwang Qi.

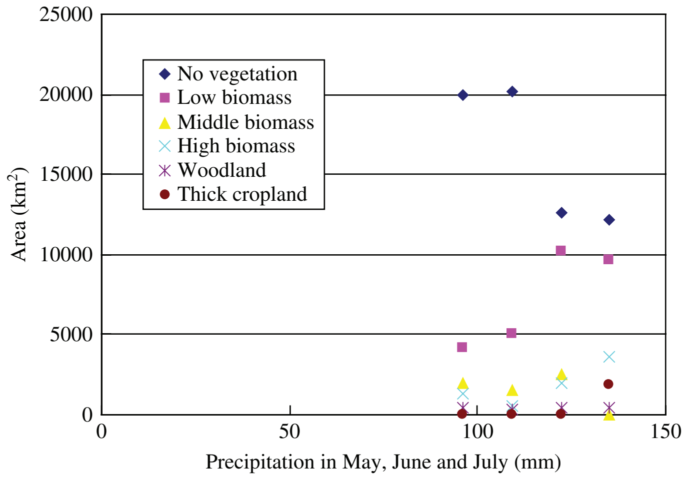


Figure 9: Relationship between biomass and precipitation.

zone because of a delay in the 2002 harvest. The area of low vegetative biomass is in good proportion to precipitation, and the areas of middle vegetative biomass and high vegetative biomass are in proportion to precipitation to some extent. The area of the no or slight biomass class is in inverse proportion to precipitation.

## 6 CONCLUSIONS AND PROSPECTS

In this study, desertification was assessed on the basis of vegetative biomass derived from four Landsat TM/ETM+ data sets. The area of each biomass zone did not change with time. Seventy-two percent of the study area was classified into the no or slight vegetation zone in 1989 and 1997, and 44–45% in 1994 and 2002. The total areas of no or slight vegetation and low-vegetative biomass zones were 78–91% in 1989, 1994, 1997, and 2002.

Vegetation growth is greatly affected by differences in distribution and the pattern of precipitation. The precipitation from May to July controls the growth of vegetation in the study area, particularly for perennial plants. However, annual plants can sprout immediately after a certain precipitation. Therefore, the conditions of steppe vegetation cover cannot be determined solely by changes in biomass.

The area of no-or-slight-vegetation category is in inverse proportion to precipitation, whereas the area of low-vegetative-biomass zone is in proportion to precipitation. The increase in population increased food demand. As a result, the population of small livestock (sheep and goats) has increased significantly since 1992. It can be concluded that the degradation of grasslands and desertification are related to both human activities and weather conditions. Land use in semiarid regions should be regulated by managing agricultural activities and restoring grasslands and woodlands.

The study area lies in a zone for both farming and livestock breeding. The relationship between humans and water is another important issue, following the relationship between humans and land. Even if vegetative biomass increases, the rapid increase in population may have a negative effect on the environment. Therefore, proper land use is important for sustainable agriculture and livestock farming and for the conservation of semiarid ecosystem.

Population, efficiency of water usage, and land productivity are the three key factors responsible for desertification in the semiarid steppes of Inner Mongolia. In our future study, these factors will be systematically analyzed, in relation to regional socioeconomic development and management policies for the population and land.

## ACKNOWLEDGEMENTS

This study was supported by the research fund of the Dalian Nationalities University (20066207), by the Global Environment Research Fund of the Ministry of the Environment in Japan (C-052 ‘Synthetic evaluation of the effect of acidic load on material flows in East Asian catchments areas’) and by the research fund of the Core Research for Evolution Science and Technology ‘Modeling global hydrological cycles and world water resources coupled with human activities’.

## REFERENCES

[1] Lee, W.-T., *The Face of the Earth as Seen from the Air: A Study in the Application of Airplane Photography to Geography*, American Geographical Society: New York, Special Publication 4, 1922.

[2] Townshend, J.R.G., Justice, C.O. & Kalb, V.T., Characterization and classification of South America land cover types using satellite data. *International Journal of Remote Sensing*, **8**, pp. 1189–1207, 1987.

[3] Tucker, C.J., Townshend, J.R.G. & Goff, T.E., Africa land cover classification using satellite data. *Science*, **227**, pp. 369–375, 1985.

[4] Loveland, T.R. & Belward, A.S., The IGBP-DIS global 1 km land cover data set, DISCover: first results. *International Journal of Remote Sensing*, **18**(15), pp. 3289–3295, 1997.

[5] Sellers, P.J., Los, S.O. & Tucker, C.J., A revised land surface parameterization (SiB2) for atmospheric GCMs – Part II: The generation of global fields of terrestrial biophysical parameters from satellite data. *Journal of Climate*, **9**, pp. 706–737, 1996.

[6] Yang, L., Weily, B.K. & Tieszen, L.L., An analysis of relationships among climate forcing and time integrated NDVI of grasslands over the U.S. Northern and Central Great Plains. *Remote Sensing of Environment*, **65**, pp. 25–37, 1998.

[7] Wuyunna & Okamoto, K., Degeneration of steppe vegetation and the sandy desertification in Inner Mongolia, China. *Journal of the Society of Vegetation Science*, **8**, pp. 17–25, 2004 (in Japanese with English abstract).

[8] Ichii, K., Matsui, Y., Yamaguchi, Y. & Ogawa, K., Comparison of global net primary production trends obtained from satellite-based normalized difference vegetation index and carbon cycle model. *Global Biogeochemical Cycle*, **15(2)**, pp. 351–363, 2001.

[9] Kauth, R.J. & Thomas, G.S., The tasseled cap – a graphic description of the spectral-temporal development of agricultural crops as seen by Landsat. *Machine Processing of Remotely Sensed Data*, pp. 41–51, 1976.

[10] Editorial Committee of Series Resources Maps of Inner Mongolia Autonomous Region, *Series Resources Maps of Inner Mongolia Autonomous Region*, Science Press: Beijing, ISBN 7-03-002649-7, 1991.

[11] Han, N., Jiang, G. & Li, W., *The Editorial Boards of Management of the Degraded Ecosystems in Xilingol Biosphere Reserve*, QingHua University Press: Beijing, 2002.