Mongolian Journal of Biological Sciences 2003 Vol. 1(2): 25-32

Time–series Satellite Data Analysis for Assessment of Vegetation Cover in Mongolia

Naidansuren Erdenesaikhan

Environ LLC., Bayanzurkh district, XII Micro-district,Bldg.1-11, Ulaanbaatar, Mongolia
e-mail: Erdes@environ.mn

Abstract

Vegetation cover and its dynamics and trends are of interest for many: starting from herders, crop farmers and wildlife managers to decision makers, planners and wide profile of scientists. Discussed here is an attempt to assess the vegetation temporal dynamics using time series NOAA satellite 1 km data that cover the territory of Mongolia in the period of 1989 – 2002. Normalized Differences Vegetation Index (NDVI) and Departure from Average methods were employed to assess the vegetation cover status and its changes and trends over 14 years. The author has used raw data from the NOAA satellite active archive for this study and processed through Erdas Imagine and ArcGIS software packages. This study can be useful tool for land, pasture, wildlife managers and others interested in vegetation cover changes over vast areas of Mongolia and valuable in case where lack of vegetation data.

Key words: Vegetation cover, satellite data, NDVI, departure from average

Introduction

Mongolia is a land-locked country located in Central Asia between Russia and China. The climate is continental with harsh winters and hot, short summers. The total population of Mongolia is 2.3 million with an area of 1.565 million sq. km, making it one of the lowest population density areas (1.5 persons per sq. km) in the world. The main economy is nomadic animal husbandry with 33.4% GDP. Of the work force, 48.6% is in the livestock-breeding sector. Until 1990, Mongolia had a central economy with state owned farms of cattle, sheep, goat, camels and horses. There were also state-supported monitoring systems for livestock production, water supply and pasture quality. After 1990 Mongolia shifted towards a market-economy, privatization took place for much of the state owned properties and former structures for monitoring failed to function effectively. Privatization has stimulated the livestock industry, which has reached its maximum and pastureland has approached its maximum carrying capacity (Erdenebaatar *et al*., 2001). Recent extreme climate variations and pastureland deterioration brought waves of problems in this sector: high livestock mortality; decrease in pasture productivity; increase in livestock disease and as a result, a dramatic decrease in lifestyle quality for herders' families. Currently, livestock managers need accurate and timely data on vegetation conditions in their pasturelands (Tserendash, 2000). Despite the constitution statement of the country that "livestock is under care of the state" the government is not able to provide essential information for herders to assist them in ways of sustainable livestock breeding. It is very time-consuming and expensive to use ground measurements in a repetitive manner to assess pastureland productivity and quality over vast areas, which makes it unaffordable for the central and local governments as well as the individuals.

Remote Sensing for Pasture Management

The time–series information about location and condition of the vegetation of pasture areas is one of the key elements for effective management of pastoral (extensive) livestock production. Remotely sensed data derived from satellites have successfully been used for decades in assessment of pastureland productivity, predicting biomass and monitoring vegetation health status (Reeves, 2001) in temporal and spatial scales and proved to be economically feasible measurements (Tueller, 1989).

Many researchers have studied vegetation growth and its productivity in two different directions. One is to establish empirical relationships between spectral reflectance and biomass (Tucker *et al*., 1983; Wylie *et al*., 1995) the other is the use of spectral reflectance to estimate the amount of absorbed photosynthetically active radiation (Choudhury, 1987; Franklin, 2001) for ecosystem modelling. The first method is mainly used to estimate active growing biomass and the estimated biomass is well correlated with remotely sensed vegetation indices (Tucker *et al*., 1983; Kennedy, 1989; Thoma, 1998). However, this method does not take the existing dry mass into account (Reeves, 2001). The second method is more successful for predicting biomass, but is based on regression models and depends on local environmental parameters (Kennedy, 1989; Merill *et al*., 1993; Wylie *et al*., 1996).

Researchers use coarse-to-high-resolution satellite and aerial images with a ground scale of 0.2 to 60 meters (Wylie *et al.*, 1995; Yool *et al*., 1997; Weber, 2001) for pastureland assessment. However, the barriers in the use of high-resolution data are data availability and high processing cost. Nevertheless, there exist good prospects to apply low spatial resolution (ranging from 250 m to 1 km) remote sensing data for assessment of a wide area of vegetation cover. High temporal resolution (for over 20 years), wide area coverage, and availability/affordability make NOAA/ AVHRR satellite images attractive for application in pasture assessment in the context of Mongolia.

A few studies have taken place in Mongolia to estimate pastureland and vegetation dynamics from the remote sensing viewpoint. Purevdorj (1995) has studied seasonal growth changes using NOAA AVHRR data, taking into account the soil background reflectance and percent vegetation cover. As a result, monthly green vegetation cover images were produced based on global land 1 km AVHRR data in 1995.

The information presented here is intended to bring NDVI time-series measurement as first–aid hands-on tool for those in the agricultural sector of the country who lack essential vegetation status data for nomadic livestock management

NOAA AVHRR pre-processing

Multi-temporal NOAA 9, 10, 11, 14 and 16 dataset from the NOAA Satellite Active Archive (SAA) were used for this study. The period from 1989 to 2001 was analyzed, except for 1994 data that did not exist for Mongolia in the SAA database. Data were processed using image- processing Erdas–Imagine 8.5 (ERDAS Inc 2001) and ArcGIS (ESRI 2001) systems software.

Only the afternoon pass of NOAA series images were collected within the time frame of July 1 to August 15 in each year (45 images in a year), which coincide with the season of maximum vegetation growth (Tserendash, 1996). Due to extensive cloud coverage and high off-nadir areas in 1993 and 1996, the time frame was expanded from June 20^{th} to August 20^{th} to capture additional images. This extension could cause higher variability of vegetation spectral responses (Jensen, 2000) because Mongolia's frost seasons starts in August (NAP 1991), which can contribute to early vegetation senescence and thus decrease the vegetation spectral response compared to other years.

Image Registration

Raw images were registered through image-to-image registration procedures using 25 ground control points on average that were taken from existing vector coverage of lake, river and current administrative boundary of Mongolia. Depending on the satellite nominal flight height, images were distorted differently according to the surface curvature and that influenced the use of 2^{nd} and 3^{rd} polynomial orders, where applicable. To keep original values, the nearest neighbor method was used for resampling.

AVHRR Data Correction

Estimation of the spectral properties of vegetation cover using remote sensing methods have been successful for many applications. However, extensive processing efforts related to geometric and atmospheric corrections are required. The basic sun angle correction 1/cosine (sun angle) and afternoon pass selection procedure were applied for each image data to decrease the influence of different sun elevations and bi-directional reflectance distribution function (BDRD). The inter-satellite calibration factors, which aim to normalize the satellite at–sensor reflectance coefficient in each satellite have been applied (CIT 1999) for each image data through the radiometric correction procedures.

Methods

Normalized Difference Vegetation Index

AVHRR–derived vegetation indices for the last three decades proved to be a useful tool in depicting the large scale distribution and phenological changes of vegetation cover over particular regions of the world (Jensen, 2000). The most common methods available for estimating vegetation spectral responses for AVHRR data are the simple difference of visible and near infrared reflectance (NIR) DVI = NIR-Visible (Gutman, 1991), simple ratio SR=NIR/Red (Birth, 1968) and NDVI (Rouse *et al*., 1974). NDVI = NIR – Visible/NIR + Visible

The principle used for the vegetation index is based on discontinuity of reflectance curve of healthy green vegetation at the 0.7-mkm regions. Green vegetation absorbs and reflects more energy in the visible red and near infrared regions whereas senescent vegetation absorbs and reflects less in those regions.

Based on these properties, different vegetation indices were developed taking into consideration various factors of soil, vegetation density and atmospheric effects influencing outputs (Rouse *et al*., 1974; Sellers *et al*, 1994; Hall *et al*, 1995). Compared to the simple difference and ratio of NIR and Visible bands, NDVI is less influenced from sun angle and illumination and thus, provides relatively reliable information about photosynthetic processes going on in green vegetation (Gutman, 1991).

Maximum NDVI Decision Rule

NDVI has been calculated for each of the image scenes in a year and the the maximum NDVI decision rule (Holben, 1986; Spanner *et al*., 1990; Burgan, 1993; Roberts, 1994) applied to reduce cloud-contaminated pixels in image scenes and to eliminate the differences of vegetation spectral responses due to phenological processes captured in the long compositing period. Maximum NDVI decision rule employs the selection of highest NDVI pixel values from a scene to make a composite consisting of maximum reflectance of the image area over the chosen period of time. The compositing period of images was 45 days and phenological variability of vegetation cover within this period was then apparent (Reed, 1994) during the process of composition. This could be a potential for misinterpreting inter-annual variability of vegetation cover, therefore, application of maximum NDVI was necessary to avoid this type of error.

Departure from Average Vegetation Greenness

Long-term time series image data provides an opportunity to assess quantitatively and qualitatively the vegetation cover status in the past and present, to determine trends and to predict ecosystem processes (Nemani *et al*., 1997). An average of thirteen year NDVI data was computed for each image pixel and departure from its average was then calculated for each participating year to evaluate a yearly vegetation growth rate or greenness visually and statistically. The algorithm to produce the departure from average (Burgan, 1996) is:

$Dep_i = NDVI_{cur}/NDVI_{aveg} * 100$

Where,

Dep_i: i^{th} pixel's departure value

$NDVI_{cur}$: current NDVI

$NDVI_{aveg}$: 12-year average NDVI

100: a multiplier to scale the output to be 100 if there is no departure

Departure from average vegetation greenness can be applied for inter-annual assessment of vegetation cover status over the whole of Mongolia. This temporally and spatially distributed information provides support to decision makers, planners and agricultural managers and allows a comparison each year in terms of vegetation growth, stress and productivity. It allows effective resource allocation and avoids overgrazing.

Results

Vegetation Greenness Distribution

As a parameter well correlated with ongoing photosynthetic process in vegetation, NDVI higher values ranging 0.5-0.7 were distributed over the north-central part of the country which is predominantly forest cover. NDVI 0.3- 0.49 values are mainly distributed in forest fringe areas extending from north- central to east of the country. Lower values of 0.1-0.29 dominate centrally and ranged from west to east. The lowest values are associated with Gobi desert and Great Lakes Depression. With some annual variation, NDVI spatial distribution confirms the boundary and extent of dominant natural ecological zones

(Ramsey *et al*., 1995; Anonymous, 1998). Despite efforts to minimize influence of undesirable noises, some areas of Huvsgul, Hangai and Hentii mountainous taiga and forest regions still have cloud coverage on some images. Clouds are regular in these regions and cause an obstacle for optical remote sensing devices. According to the annual solar radiation map, cloudless days in these areas are sixty (NAP, 1991).

The lowest values of standard deviation are distributed over the Gobi desert and Great Lakes Depression. The sandy areas with sparse vegetation areas are more stable in terms of spectral response over time. It is obvious that the changes in vegetation dynamics are a direct function of precipitation and temperature in a particular year (Ichii *et al*., 2002). Accurate climate data provide explanations for these variations.

Transition Matrix of NDVI classes 2000 - 2001

Classes	1 NDVI<0	2 NDVI 0.001-0.009	3 NDVI 0.1-0.19	4 NDVI 0.2-0.29	5 NDVI 0.3-0.39	6 NDVI 0.4-0.49	7 NDVI > 0.5	Increased in 2001
2000								
1	**410791**							18918 (4.4%)
2		**226797**						
3			**159329**					
4				**145069**				3111(2.1%)
5					**164971**			
6						**208063**		
7							**221733**	16741
Decreased in 2001		712 (0.31%)	1475 (0.91%)		12893 (7.25%)	21562 (9.4%)		

Clustering (ISODATA) with 7 classes of NDVI values ranging from 0.001 to 0.7 and 6 iterations (convergence threshold 0.95) was carried out to assess spatial distribution of NDVI quantitatively, over entire area of Mongolia for each scene.

Transitional matrix is calculated based on the clusters to assess annual change of NDVI classes.

The spectral responses of vegetation cover in 2001 were lower in all classes, except class 4. Main decreases were in classes 5 (7.25%) and 6 (9.4%) compared to 2000, whereas the class with no NDVI response was increased by 4.4%. Overall, the cluster classes and transitional matrix show the decrease in vegetation spectral responses from 2000 to 2001.

Standard deviation of pixel values for 12 years has been plotted (Fig.1) to exhibit the variability. Variation of spectral responses was very high from north to south and west to east spatially and this also applied temporally.

Distribution of high standard deviations is shown in the northern half of the country, including high mountains, taiga forest, and steppe areas. All forested areas, except Hentii mountain region, have high spectral variations; the cause can be the changes in precipitation, temperature fluctuations as well as human induced disturbance factors. It is interesting to observe the similar high variability in Eastern steppe areas as well as in high elevation mountainous areas in westernmost Bayan-Ulgii Province, despite their distinctive ecosystem.

Average Greenness and Departure from Average

Departure from Average Vegetation Greenness method was employed to assess the changes in spectral responses of vegetation growth, from year to year. Yearly assessment of grass growth and biomass on a broad scale and its comparison to other years has practical implications for correct allocation of pasture resources, pastureland conservation and justification of livestock numbers. After screening for quality, eleven consecutive years AVHRR NDVI data, except 1989 and 1996 where some coverage was missed, were averaged to create the average greenness image (Fig.2). Then the average image has been subtracted from each annual composite of images. The departure values on an image composite range between 0-255 and value 100 $\pm$ 10 % represents no change from average. Values over 100 relate to positive change i.e. more growth than the average and have been assigned light and dark green colors. Values below 100 relate to negative change and have yellow (10-20% below average) and red (more than 20% below average).

The image differencing technique (Ross *et al*., 1998) has been applied to assess the vegetation growth changes over ten years, averaging the first and last two-year periods (Fig.3). The result shows spectral responses of vegetation cover in eastern steppe and central regions have negative changes and the areas of taiga forest in the north and western areas of the Great Lakes Depression have high

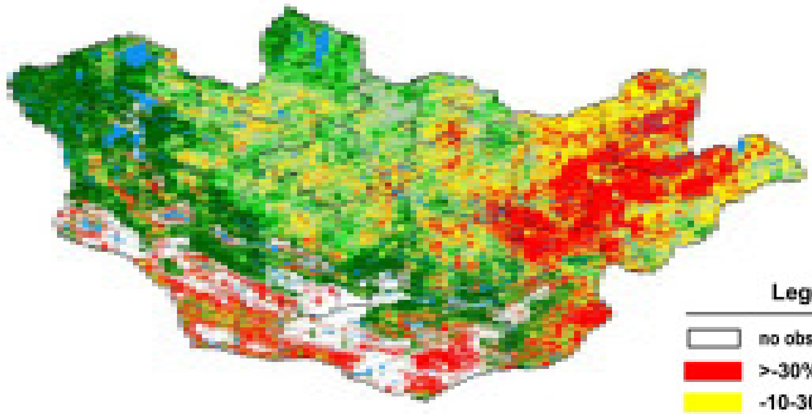
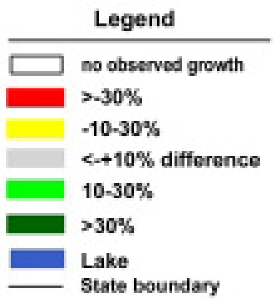

Fig. 1. Vegetation growth anomaly for 2002, Mongolia

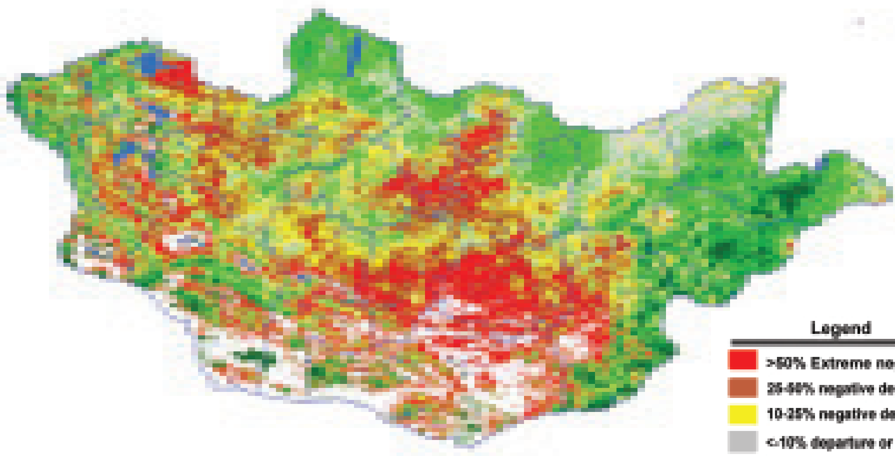
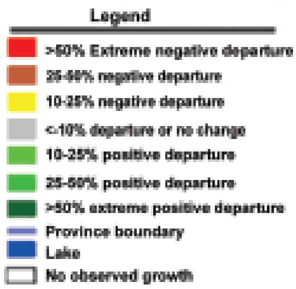

Fig. 2. NDVI Difference image of Mongolia for 1991 and 2001 (NOAA/AVHRR data)

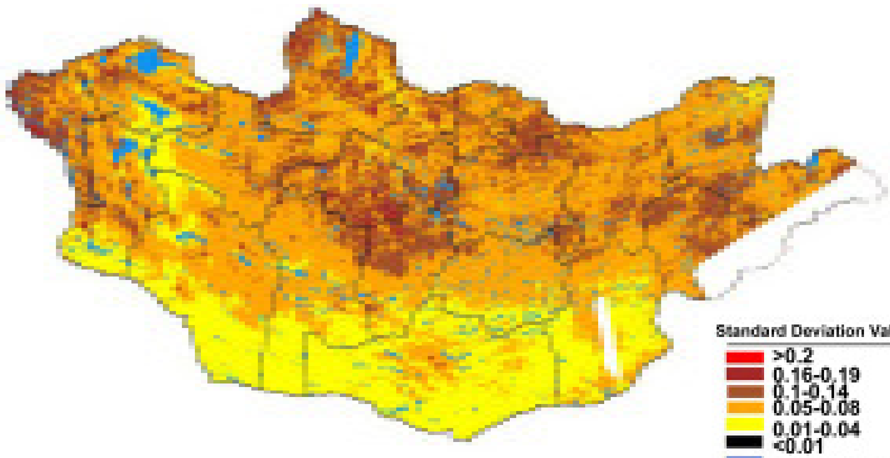
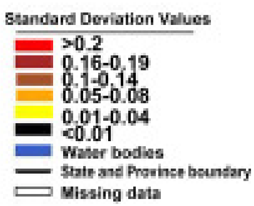

Fig. 3. Standard devation of 12 year NDVI values

spectral responses that correspond to good vegetation growth.

Discussion

As we have seen, the time series NDVI data can be applied for assessment of yearly growth dynamics in terms of vegetation stress and productivity by comparing to an average. This kind of data can be applied to predict and model ecosystem processes, provided there are appropriate supplementary data (Landsberg *et al*., 1997, Neil *et al*., 1999, Coops *et al*., 2001). In order to complete the above study it is necessary to carry out detailed ground truth measurements to assess its accuracy. This in turn requires a well-designed sampling strategy and substantial funding. Preliminary assessment after visiting 6 aimags (provinces) and comparison with other vegetation status maps developed by the Hydrometeorology Agency show good matching. Based on this finding, the output departure maps can be directly applied at all levels of decision-making in agriculture for effective resource allocation and to avoid overgrazing. Data with vegetation temporal dynamics can also be beneficial for assessment of droughts, desertification, land use status and other disturbance factors. Wildlife managers and crop farmers can benefit from this type of data to assess population dynamics, habitat, crop stress and productivity.

Conclusion

Broad scale time–series NDVI images can be applied in conjunction with traditional methods for monitoring grassland condition, temporal and spatial changes and to some extent assess grassland productivity. It is particularly useful where there is a lack of primary measurements of vegetation and pastureland conditions across large areas and where climate dependent nomadic livestock is the primary source of livelihood.

References

Anonymous 1998. Ulaanbaatar, Mongolia. 56 pp.

Birth G.S. & McVey G. 1968. Measuring the color growing turf with a reflectance spectro-photometer. *Agronomy Journal*, 60: 640-643.

Burgan R.E. & Hartford R.A. 1993. Monitoring vegetation greenness with satellite data. Gen. Tech. Rep. INT-297. Ogden, UT:U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 13 pp.

Burgan R.E., Hartford R.A. & Eidenshink J.C. 1996. Using NDVI to assess departure from average greenness and its relation to fire business. Gen. Tech. Rep. INT-GTR-333. Ogden, UT:U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 8 pp.

Cohen, W.B. & Fiorella M. 1998. Comparison of methods for detecting conifer forest change with thematic mapper imagery. *Remote sensing change detection*. Ann Arbor Press. pp. 89-102

Coops N.C. & Waring R.H.. 2001. The use of remote sensing imagery to derive regional estimates of forest growth capacity using 3-PGS. *Remote Sensing of Environment* 75: 324-334.

Choudhury, B.J. 1987. Relationships between vegetation indices, radiation absorption, and net photosynthesis evaluated by a sensitivity analysis. *Remote Sensing of Environment* 22: 209-233.

Erdas. Inc. 2001. Erdas-imagine v. 8.5 Image processing application manual.

Erdenebaatar B. & Batjargal N. 2001. Disputes of pasture ownership. Ulaan Baatar. Mongolia. (In Mongolian).

ESRI. 2001. ArcGIS software manual.

Franklin S.E. 2001. *Remote sensing for sustainable forest management*. Boca Raton, Florida, Lewis Publishers.

Gutman G.G. 1991. Vegetation indices from AVHRR: An update and future prospects. *Remote Sensing of Environment* 35: 121-136.

Hall F.G., Townsend J.R., & Engmann E.T. 1995. Status of remote sensing algorithms for estimation of land surface parameters. *Remote Sensing of Environment* 51: 138-156.

Holben, B.N. 1986. Characteristics of maximum-value composite images from temporal AVHRR data. *International Journal of Remote Sensing* 7(11): 1417-1434.

Jensen J.R., 2000. *Remote Sensing of the Environment*: An Earth Resource Respective, Prentice Hall, Upper Saddle River, New Jersey.

Ichii K., Akira K. & Yasushi Y. 2002. Global correlation analysis for NDVI and climatic variables and NDVI trends: 1982 to 1990.

International journal of remote sensing (in press).

Kennedy P.1989. Monitoring the vegetation of Tunisian grazing lands using the normalized difference vegetation index. *Ambio* 18: 119-123.

Landsberg J.J. & Waring R.H. 1997. A generalized model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance and portioning. *Forest Ecology and Management* 95: 209-228.

Merrill E.H., Bramble-Brodahl M.K., Marrs R.W. & Boyce M.S.1993. Estimation of green herbaceous phytomass from Landsat MSS data in Yellowstone National Park. *J. Range Management* 46: 151-157.

NOAA/NASA AVHRR Pathfinder Oceans –GAC product Generation Appendix. California Institute of Technology, 1999

National Atlas of Mongolia. 1991. Ulaanbaatar, Mongolia

Lucas N.S. & Curran P.J. 1999. Forest ecosystem simulation modelling: the role of remote sensing. *Progress in Physical Geography* 23(3): 391-423.

Nemani R. & Running S. 1997. Land cover characterization using multitemporal red, near–ir and thermal-ir data from NOAA/AVHRR. *Ecological Applications* 7(1): 79-90.

Reeves M.C., Winslow J.C. & Running S.W. 2001. Mapping weekly rangeland vegetation productivity using MODIS algorithms. *J. Range Management* 54: 90-105

Reed B.C., Brown J.F., VanderZee D., Loveland T.R., Merchant J.W. & Ohlen D.O. 1994. Measuring phenological variability from satellite imagery. *Journal of Vegetation Sceince* 5: 703-714.

Roberts M. & Doyle T.W. 1994. Component Analysis for interpretation of time series NDVI imagery. ASPRS/ACSM

Rouse J.W., Haas R.H., Schell J.A. & Deering D.W. 1974. Monitoring Vegetation Systems in the Great Plains with ERTS. Proceedings, Third Earth Resources Technology Satellite-1 Symposium, Greenbelt: NASA SP-351, 3010-317

Sellers P.J., Los S.O., Tucker C.J. 1994. A global 1^0 by 1^0 NDVI data set for climate studies. Part. 2: The adjustment of the NDVI and generation of global fields of terrestrial biophysical parameters. *Int. J. Remote Sens.* 11: 95-111.

Spanner M.A., Rierce L.L., Running S.W. & Peterson D.L. 1990. The seasonality of AVHRR data of temperate coniferous forests: Relationship with leaf area index. *Remote Sensing of Environment* 33: 97-112.

Thoma D.1998. Near real-time satellite and ground based radiometric estimation of vegetation biomass, and nitrogen content in Montana rangelands. MSc Thesis. Montana State University, Bozeman Mont.

Tserendash S. 2000. Some policy related issues for pasture management. Newsletter No. 6 (38). Mongolian Academy of Sciences.

Tueller P.T. 1989. Remote sensing technology for rangeland management. *J. Range Management* 42: 442-452

Weber K.T. 2001. A method to incorporate phenology into land cover change analysis. *J. Range Management* 54: A1-A7

Wylie B.K., Denda I., Pieper R.D., Harringston J.A., Reed B.C. & Southward G.M. 1995. Satellite-based herbaceous biomass estimates in the pastoral zone of Niger. *J. Range Management* 48:159-164.

Yool S.R., Makaio M.J. & Watts J.M. 1997. Techniques for computer–assisted mapping of rangeland change. *J. Range Management* 50: 307-314.

Received: November 2003
Accepted: December 2003

Хураангуй

Ургамлын бүрхүүл болон түүний динамик өөрчлөлт, ирээдүйн хандлага нь малчид, тариаланчид, анчид, амьтан судлаач, хамгаалагчдаас эхлэн шийдвэр гаргагчид, төлөвлөгчид, судлаачдын анхаарлын төвд байдаг асуудлын нэг билээ. Энэхүү судалгаа нь 1989 оноос 2002 он хүртэл ургамлын бүрхүүлийн динамик цаг хугацааны туршид хэрхэн өөрчлөгдөж буйг НОАА хиймэл дагуулын нэг километрийн ялгах чадвартай мэдээгээр үнэлэх анхны оролдлого юм. Ургамлын индексийн нормчлогдсон ялгаа, дунджын хазайц зэрэг аргуудыг хэрэглэн Монгол орны ургамлын бүрхүүлийн байдал, өөрчлөлтийг 14 жилийн хугацаанд тодорхойллоо. Судлаач АНУ-ын Далай агаар мандлын захиргааны хиймэл дагуулын нээлттэй архиваас эх мэдээг авч дүрс боловсруулалтын Erdas Imagine болон Газарзүйн

мэдээллийн системийн ArcGIS програм хангамжуудыг ашиглан боловсруулалт хийж энэ судалгаандаа ашиглажээ. Уг судалгааны үр дүнг газар зохион байгуулагч, бэлчээрийн мэргэжилтэн, ан амьтан хамгаалагч болон бусад холбогдох мэргэжлийн хүмүүс өөрийн ажилдаа хэрэглэх боломжтой бөгөөд ургамлын бүрхүүлийн талаар газрын хэмжилтийн үнэн зөв мэдээлэл байхгүй тохиолдолд чухал ач холбогдолтой.