Vegetation estimation using Normalized Difference Vegetation Index (NDVI) from satellite NOAA/AVHRR data over Mongolia.

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Abstract

The purpose of this research work was to estimate the vegetation cover and to compare the satellite images and stations data. NOAA-AVHRR derived NDVI will be used for assessing the vegetation. Global NDVI data sets of GAC data were used in comparison of NDVI over the good and deficit rain years in order to develop an understanding of the response. The information is useful in showing the trend of crop yields and pasture crops and conditions of arable land and pasture in Mongolia.

Introduction:

Mongolia is an agricultural country. Therefore, the estimation of the vegetation cover is highly useful in Mongolian agriculture.

The vegetation is a sensitive indicator of many ecosystem properties influencing the energy balance, climate, hydrology and biogeochemical cycles. In order to understand the functioning of the earth as a whole system, an understanding of the global distribution of vegetation types, as well as, their biophysical properties and temporal variation is required.

The vegetation plays an important role in the transfer of matter and energy from the earth's surface to the atmosphere. Interaction between land surface and the atmosphere and the resulting exchanges of energy and water have a large effect on climate (Sukla & Mintz, 1983). The vegetation is in its various forms (forests, grasslands, agricultural areas, etc.) an important component of the earth scene. It has been found that the information of fine structure of a leaf spectrum as measured in the laboratory is insufficient to account for the reflectance of plant canopies. Attenuation and multiple scattering of radiation within a plant canopy, as well as the influence of soil, shadow and other background spectral properties complicate the vegetation response.

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A vegetation canopy is characterized by its leaves square, height, development, vegetation cover, leaf orientation angle etc. whereas, the soil optical properties, surface roughness, soil type, surface soil moisture, surface soil temperature etc characterize the soil surface. All these factors collectively determine the nature of the interaction with incidental solar radiation. Consequently, the received signal from satellite contains information on the state and composition of soil moisture (availability), vegetation and atmosphere. During the life cycle of crops, the geographical and optical properties of the crops undergo changes. As a result, crop interacts differently with the incident solar radiation at each stage of its life cycle. Characterization of the temporal pattern of crop reflectance characteristics in relation to leaf area index, crop height, leaf optical properties, surface soil moisture condition, surface soil temperature and incident solar radiation can provide valuable information regarding crop health, development and yields.

A single leaf reflects, absorbs, and transmits incident radiation in a manner that is uniquely characteristic of pigmented cells containing water. Only a part of the incident energy is reflected from a leaf, the remainder is either absorbed or transmitted. These three components are closely interrelated and must be considered together. Three regions in the range 0.4-2.5 μm may be distinguished with respect to interaction of a leaf with electromagnetic energy, namely visible (0.4-0.7 μm), near-infrared (0.7-1.3 μm) and middle-infrared (1.3-2.5 μm).

In the visible wavelengths, approximately 2-3 percent of incident radiation or about half of the total reflectance is reflected from the surface (cuticle) of the leaves and does not enter or interact with the leaf (Wooley, 1971). Much of this reflectance is specular, rather than diffuse. The amount and nature of cuticular reflectance depends on surface (wax layer) characteristics, which are uniquely related to species, leaves age, environmental conditions (stresses) etc. The specular contribution to reflectance increases with angle of incidence (Breece and Holmes, 1971).

In the VIS range the absorption of EM by plant pigments such as chlorophyll (green pigment), xanthophyll (yellow pigment) and carotene (orange pigment) determines the reflectance characteristics. Of these three pigments, chlorophyll is the dominant pigment and persists in two major forms, chlorophyll a and b. Each pigment has absorption maximum in the 0.30-0.50 μm region, however, only chlorophyll absorbs in the red region. Principle absorption peaks of extracted chlorophyll a occurs at 430 nm and 660 nm and that of chlorophyll b at 455 and 640 nm. When measured in vivo these peaks shift approximately 20 nm towards the longer wavelengths owing to the difference in the refractive indices between the extract solvent and leaves water.

The evidence for the internal reflectance mechanism in 0.7-1.3 μm range is given by the drastic reduction of leaf reflectance infiltrated with water (Knipling, 1970), which leads to filling of air cavities and elimination of refractive index differences responsible for NIR reflectance. In the middle infrared area (1.3-2.6 μm) of the spectrum, the reflectance of green vegetation is dominated by strong water absorption bands, which occur near 1.4, 1.9 and 2.7 μm; however, the regions between these absorption bands are also influenced by water content of leaves. In addition there are weak absorption bands of water at 1.1 and 0.96 μm. In this region, leaf reflectance is inversely related to the total amount of water present in the leaf and the spectral absorption characteristics can be simulated by the absorption of an equivalent water thickness (Tucker, 1980). When the leaves dry up the reflectance in this region will increase. Differences in reflectance in this region amongst different types of vegetation as well as crops, such as broadleaf vs conifer needles or wheat and mustard and add to discrimination capability from space.

As leaves expand and mature their visible reflectance decreases and near-infrared reflectance increases. This effect is attributed to the greater number of intercellular air spaces in the mesophyll of mature leaves compared to those of young compact leaves. Senescence produces the opposite effect of maturation, i.e., visible reflectance increases due to loss of chlorophyll and infrared reflectance decreases, although relatively less than the increase in visible reflectance. The optical properties of plant leaves are also affected by various kinds of stresses including nutrient deficiencies, salinity, water deficits and damage by insects and diseases. These stresses are typically accompanied by reduced chlorophyll production causing increased reflectance in the visible region. In the infrared, reflectance is generally reduced, although loss of water results in increased infrared reflectance.

Fundamentally the spectral reflectance of crops and other vegetation canopies are determined by five physical factors (Bauer, 1985):

1. Leaf optical properties
2. Canopy geometry, particularly leaf area index and leaf angle distribution
3. Soil background reflectance
4. Solar illumination and view angles
5. Atmospheric transmittance.

The canopy geometry describes how the individual scattering and absorbing elements are positioned throughout the canopy, and is thus a major determinant of the radiation transfer within and from canopy. The geometrical arrangement of plant foliage in space varies according to species, cultivars, cultural practices (such as planting density, row width, and fertilization) and environmental factors (such as moisture stress, disease or insect damage and wind). Although it is difficult to characterize the complex geometry of vegetation canopies, three most commonly used physical parameters are leaf area index (LAI), percent soil cover and leaf angle distribution (LAD). LAI is the total one-sided leaf area per unit of ground area. Soil cover is defined as the percentage of soil obscured by the vegetation when viewing the canopy thus depends on LAI, leaf angle and row width. LAD is cumulative frequency distribution of leaf angles.

The vegetation normally estimates using vegetation indices, which are dimensionless, radiometric measures usually involving a ratio and/or linear combination of the red and near-infrared (NIR) portions of the spectrum. Vegetation indices serve as indicators of relative growth and/or vigour of green vegetation and are diagnostic of various biophysical vegetation parameters such as leaf area index (LAI), % green cover, green biomass and absorbed photosynthetically active radiation (APAR), canopy photosynthesis, stomatal conductance and land surface albedo. Also as a result of different arithmetic combinations the vegetation indices reduce the additive and multiplicative errors associated with atmospheric effect and sensor characteristics. The criteria for and definition of a vegetation index includes:

- The index should maximize the sensitivity to plant biophysical parameters, preferably with a linear response.
- The index should normalize the external effects such as sun angle, viewing angle, clouds and atmosphere.
- The index should minimize the ground contamination caused by canopy background variations and differences in senesced and woody vegetation.
- The index should be a global product, allowing spatial and temporal comparison of vegetation conditions.
- The index should be coupled to a key biophysical parameter such as LAI or APAR.

The earlier developed (pre 1980s) and commonly used indices have been summarized below. Most of these vegetation indices suffer from soil brightness and atmospheric influences. So, the vegetation indices developed after these are mostly meant to be free from these effects.

Table 1.

The major vegetation indices

Name	Formula
Ratio	R_r / R_{nir}
Normalized Difference VI	$(R_r - R_{nir}) / (R_r + R_{nir})$
Transformed VI	$(NDVI+0.5)^{1/2}$
Orthogonal VI [Greenness(GVI)/Brightness(SBI)]	$a.R_{bl}+b.R_{gr}+c.R_r+d.R_{nir}$
Perpendicular VI	$[(R_r^s-R_r^p)^2+(R_{nir}^s-R_{nir}^p)^2]^{1/2}$
Ashburn VI	$2.0*R_{nir} - R_r$
GRABS	$GVI=a.SBI+b$

R_{bl}, R_{gr}, R_r, R_{nir} are the radiance values at blue, green, red and near infra-red wavelength regions the superscripts s and p stand for soil and plant, respectively.

NOAA-AVHRR data in the Red and Near Infrared are allowed to calculate the NDVI, which is useful to monitor the crop area and crop growth/stages through out the growth cycle. Thus, the temporal NDVI may be considered as an important crop elements.

For row crops, particularly at incomplete cover, the row structure and direction are additional factors influencing the reflectance. This effect controls diurnal effects on canopy reflectance. In the study by Kollenkark et al. (1982), in the NIR, the effects due to interaction of sun angle and row direction are considerably less pronounced than in highly absorptive red region. The magnitude of this reflectance difference, however, decreases with increased canopy cover.

Methodology:

For vegetation the most widely applied satellite-derived parameter is the Normalized Difference Vegetation Index (NDVI), calculated from the visible (red, channel 1) and near-infrared (channel 2) reflectivity of the Advanced Very High Resolution Radiometer (AVHRR) flown on board the polar orbit NOAA satellites.

$$NDVI = (NIR-RED) / (NIR+RED)$$

We also used some simple models for calculation of the monthly and sum NDVI of the vegetation period in Mongolia.

Used data:

- NDVI decadly (10 days) data (NOAA-AVHRR) from the Local Area Coverage (LAC) between 1984 and 1991.
- NDVI biweekly data from CD ROM from 1985 to 1991.
- Spring wheat crops in Mongolia between 1961 and 1996.
- Latitude and Longitude of four stations of Mongolia.
- Geographic, Administrative, Natural zoning, Soil, Crop areas maps of Mongolia.

Analysis procedure:

In this study we used ERDAS Imagine 8.3 software for image analysis and XV for taking pictures. Using ERDAS Imagine 8.3 software we imported NDVI NOAA-AVHRR data from CD ROM and downloaded internet NDVI for Asia continent to raster images. For import from CD ROM data we used next parameters. (Table 2)

Table 2.

Parameters for import from CD ROM data to raster.

Data set 1	Gallo Experiment Calibrated Biweekly Global Vegetation Index (from GAC NDVI of NOAA/AVHRR data)
Period of composite	Biweekly
Coverage	Global
Pixel size	10 x 10 min
Projection	Mercator
Region of Mongolia Geographic: Image coordinate	85-120^{0}E, 40-55^{0}N ULX 1507.56 ULY 286.32 LRX 1706.67 LRY 414.03
Period of data availability	April 1985 to May 1991
Period of data acquired	April 1985 to May 1991

Then, for import from downloaded Internet data we had to use parameters in Table 3.

Table 3.

Parameters for import from downloaded Internet data to raster.

Data set 2	AVHRR Patufunder data set
Period of composite	10 day maximum value
Coverage	Continent (Asia)
Pixel size	8 x 8 km
Projection	Good homolosine
Region of Mongolia Geographic: Image coordinate:	85-120^{0}E, 40-55^{0}N ULX 532 ULY 256 LRX 832 LRY 448
Period of data availability	January 1981 to December 1994
Period of data acquired	April, May, July, August 1985 and 1990

The imported source NDVI image for Asia given in Fig 1. After imported to raster images we subset the study area of Mongolia using latitude and longitude value (Fig 2).

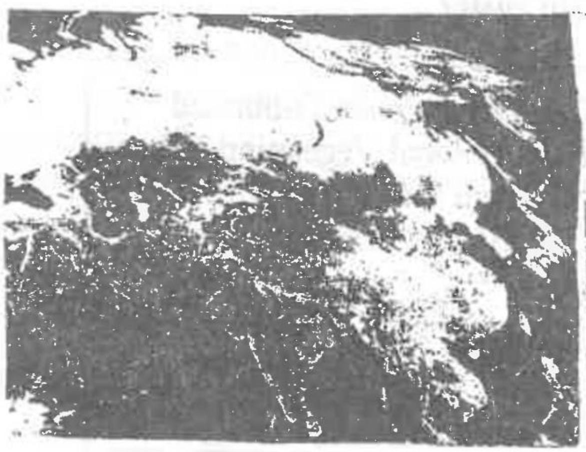


Fig 1. NDVI for the second decade of July 1985 (Asia).

Fig 2. NDVI for the second decade of July 1985 (Mongolia).

The spectral, spatial and surface profiles of NDVI have plotted for 4 stations Baruunturuun, Darkhan, Khalkh Gol and Dalanzadgad for 1985-1991.

Results and discussions:

Calculation Normalized Difference Vegetation Index (NDVI).

Using the formula for calculation of NDVI we have calculated NDVI for the growing period of plants in Mongolia for 1985-1991.

For understanding the vegetation in Mongolia during the growing period (April-September) we have plotted the spectral, spatial and surface profiles of NDVI of the same period for 4 different stations of Mongolia, which are located in different natural zones. The Baruunturuun station presents the western part of the country and the hilly agricultural area. The Darkhan station represents the central agricultural region. The Khalkh Gol station gives the condition of steppe agricultural area. The Dalanzadgad station is located in Gobi region. From then spectral, spatial and surface profiles, where added 14 decades of the growing period of plants we have got the good and bad years in agriculture of Mongolia. The spectral, spatial and surface profiles show that 1985 presents the good crop year and 1990 accords the bad crop year in Mongolian agriculture. In fig 3 gives the spectral profile for 1985 as an example. Profile 1 presents the value of the Darkhan station. Profile 2 gives the value of the Baruunturuun station. Profile 3 shows the value of the Dalanzadgad station. Profile 4 is the value of the Khalkh Gol station. The level means decade of the growing period (April-September) in Mongolia. In other words, the first level is the first decade of April 1985, the fifth level presents the second decade of May 1985 etc.

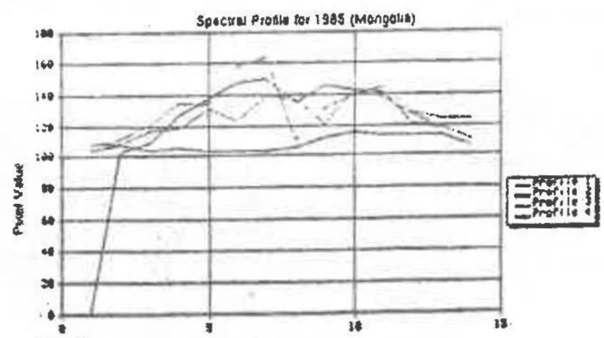


Fig 3. The spectral profile for 1985 for four stations of Mongolia.

The comparison of spectral profiles of NDVI for 1985 and 1990 shows that the vegetation in four stations is different due to agrometeorological conditions. If we look at the vegetation in these 4 stations we have the result, it shows that the vegetation in Darkhan plays the dominant role in agricultural crops of Mongolia. The vegetation in the other stations changed less in 1985 and 1990.

Monthly NDVI for 1985 and 1990 is calculated from subset Mongolia images using a simple model (Fig 4). The calculation (D*(NDVI-100)/100 where: D is the number of days, NDVI is NDVI image value) shows that the vegetation cover in 1985 in Mongolia was better than in 1990.

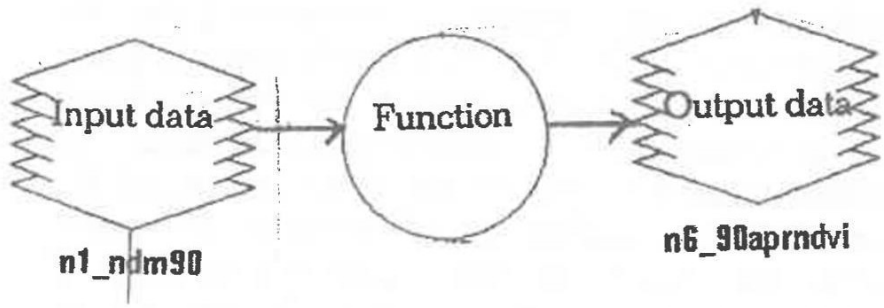


Fig 4. The simple model for calculation monthly NDVI.

In May 1985, the Mongolian area except high mountains and Gobi region had the vegetation, which can be estimated on several levels. During this period, some parts of the country were covered by very good and good vegetation in Bulgan, Selenge, Tov and Khentii provinces. The remaining parts were covered by the satisfactory and the bad vegetation. In May 1990, the northern part of Mongolia had only satisfactory and bad vegetation. During that time we could not recorded the very good and good vegetation cover. It means that in this year the plant growth started later due to dry weather conditions. If take the peak vegetation period July for these two years then we have also different vegetation.

Fig 5. NDVI for July 1985 (Mongolia).

Fig 5 shows that the Central and Eastern parts of the country had the very good and good vegetation. Other regions had the satisfactory and bad vegetation.

From Fig 6 we can see only small parts covered by the good vegetation. The remaining part mostly covered by the satisfactory and bad vegetation. Comparison of these two images shows that the vegetation cover in July 1985 was better than in 1990.

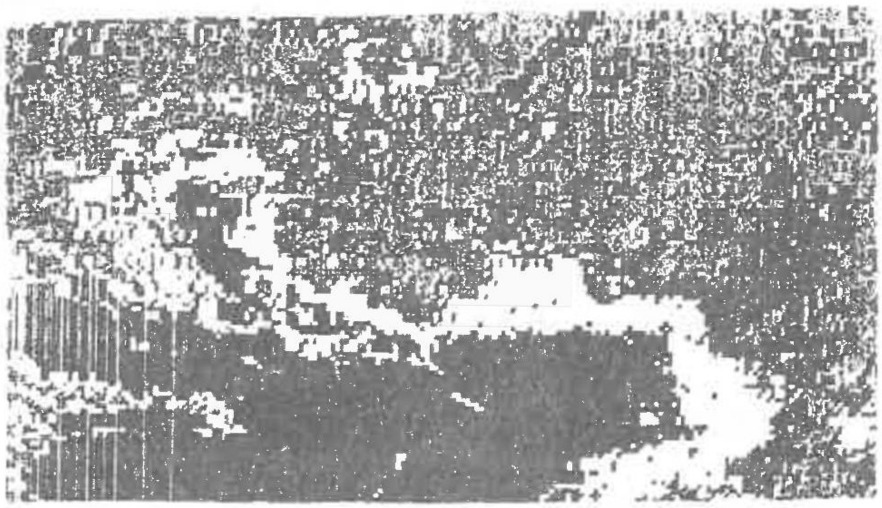
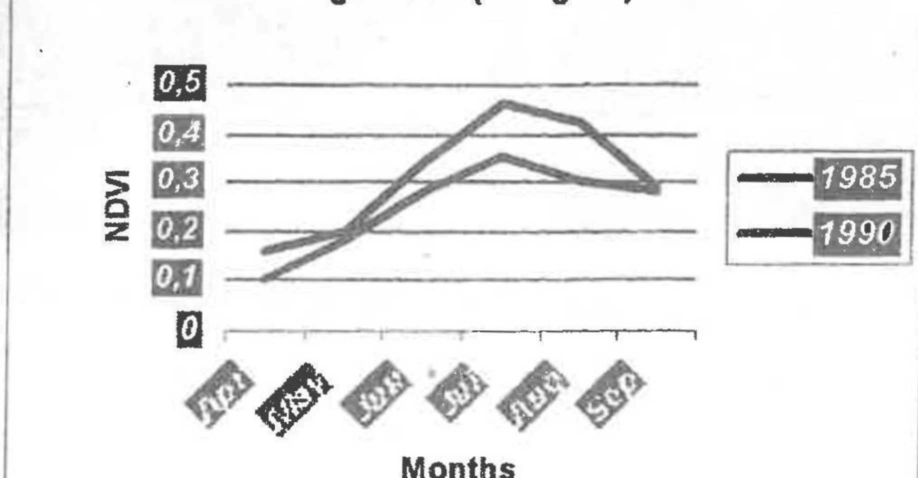


Fig 6. NDVI for July 1990 (Mongolia).

After calculation of the monthly NDVI for 1985 and 1990, we have plotted the values in Fig 7. This figure shows changes the vegetation in 1985 and 1990.

Fig 7. NDVI (Mongolia)



By using a simple model (Fig 8), we got a sum NDVI for growth period of Mongolia for 1985 and 1990.

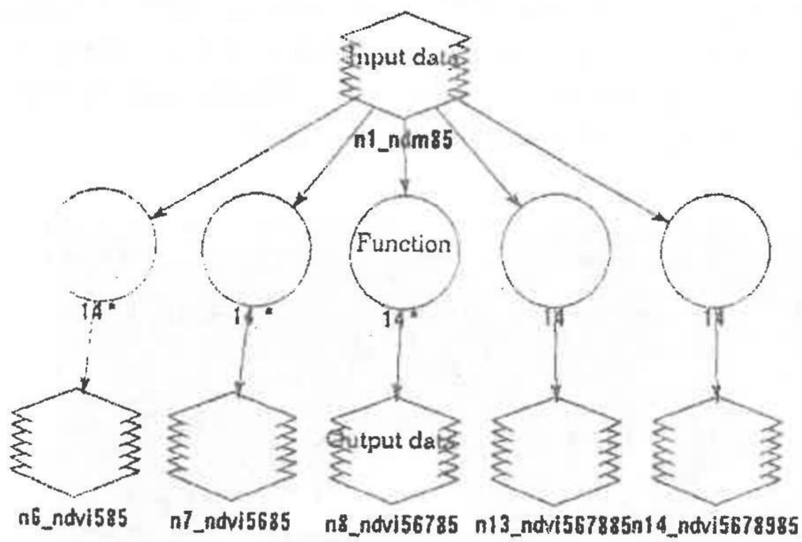


Fig 8. The simple model for calculation sum NDVI.

Calculated NDVI from May to July for 1985 and 1990 are shown. In this case 1985 has more vegetation than 1990. The sum NDVI between May and July shows that the vegetation from the beginning period up to the peak growing period. The sum NDVI for May-September 1985 (Fig 9) and 1990 (Fig 10) shows same condition as previous figures 5 and 6.

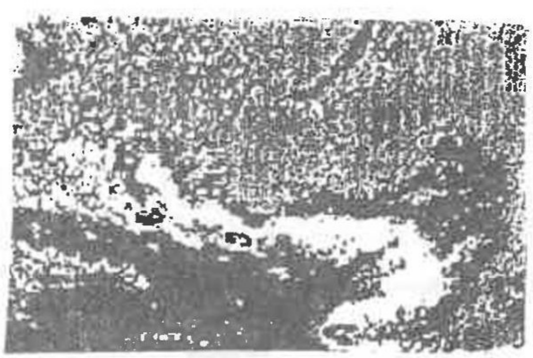


Fig 9. NDVI for May-September 1985 (Mongolia).

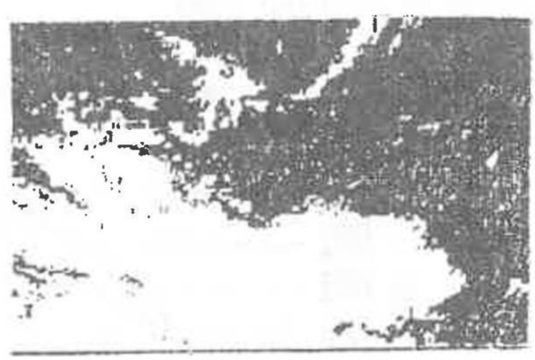


Fig 10. NDVI for May-September 1990 (Mongolia).

There the sum NDVI for May-September gives the total NDVI of the growing period in Mongolia. In the future research, the sum NDVI for May-July will be very useful for crop tendency forecasting in Mongolia. Particularly the period of May-July is the most important period for agriculture of Mongolia. If the period May-July has good soil moisture conditions, normally we get good crop. The crop yield mostly depends on weather conditions of this period. All previous NDVI calculation have been made by using the CD ROM data. Therefore, for comparison we run the simple model for the second decade of July, which is normally flowering period of plants 1985 and 1990. These figures show same position as all previous figures.

All NDVI images are estimated using values for Mongolia as very good, good, satisfactory and bad vegetation. The black colour presents very good, the black grey colour means good, the grey colour gives satisfactory and the white colour shows bad vegetation.

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Conclusions:

1. The weather condition in the beginning of growing period plays an important role in agriculture of Mongolia.
2. The agricultural crops have a strong dependence on the agrometeorological conditions in June.
3. Calculated NDVI from NOAA-AVHRR can be used in the estimation of vegetation cover.
4. Calculated sum NDVI using satellite data (for example May-July) can be show the crop tendency.

Товчлол.

Энэхүү өгүүлэлд Монгол орны ургамлын ургалтын байдлыг газрын болон хиймэл дагуулын мэдээг харьцуулан судлахыг хичээсэн болно. Түүнчлэн сарын болон ургамлын ургалтын хугацааны ургалтын индексийг (NDVI) загварын тусламжтайгаар сайн жил болох 1985, гантай жил болох 1990 оны хувьд мөн 2-5 сарын нийлбэр байдлаар тооцоолон харьцуулахын зэрэгцээ ургамлын ургалтын индексийн тухай онолын зарим ойлголтуудыг тусгалаа.

Дээрх судалгааны дунд хиймэл дагуулын мэдээг ашиглан ургамлын ургалтын байдлыг үнэлэх төдийгүй ургацын хандлагыг мэдэх боломжтой нь харагдлаа.

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