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ANALYSIS OF LANDSAT NDVI TIME SERIES FOR DETECTING LAND DEGRADATIONIN DRY CLIMATIC ZONES OF RUSSIA AND MONGOLIA

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Abstract. *Our study examines whether Landsat NDVI satellite data time series can be used to detect land degradation areas in dry climatic zones of Russia and Mongolia. Time series analysis was applied to an 25-year Landsat NDVI satellite data record, based on the hypothesis that the resulting NDVI residual trend vectors would enable successful detection of changes in photosynthetically active vegetation.*

The aim of our work is to reveal and analyze changes in the vegetation cover of Russian and Mongolian dry climatic zones using a variety of field and remote sensing methods. Model key polygons located in semiarid climatic zone of Russia and Mongolia were considered for the investigation of vegetation dynamics.

For these polygons plots of the NDVI temporal variation and NDVI maps of its spatio-temporal dynamics on the basis of TM and OLI spectroradiometer imagery (Landsat-5 and Landsat-8 satellites respectively) were constructed. The temporal dynamics of the vegetation was estimated using archive geoportal data of the Russian Space Research Institute of RAS for the period of 2001-2014. NDVI areas were mapped on the base of multitemporal satellite imagery for the first half of September from 1989 to 2014.

The full-scale landscape indication of the selected NDVI areas was conducted. This indication is supported by the analysis of vegetation by environmental groups for drought resistance. The vegetation digression during last 25 years is traced across almost the entire territory of the selected polygons.

Keywords: *desertification, vegetation degradation, semiarid, climatic zones, Landsat, NDVI, landscape indication, euxerophytes.*

Introduction

According to the definition established by the United Nations Convention to Combat Desertification (1994), the degradation of land in dry climatic zones results from desertification. While developing, the processes of desertification subsequently affect and damage the following geosystem's components: vegetation, soils and underlying rocks, and forms of the landscape. The vegetation is the first to be affected by desertification [1], so we are going to focus on studying its changes as a result of this degradation phenomenon.

The aim of this work is to reveal and analyze changes in the vegetation cover of Russian and Mongolian dry climatic zones using a variety of field and remote sensing studies.

Materials and methods

*Territory of study.*Over the years of working on the project «Development of desertification complex indication system for modern Siberian and Central Asian ecosystems and monitoring system evaluation» under the Program of fundamental scientific research, Presidium of Russian Academy of Sciences (2008-2014), a number of model monitoring polygons has been established in different climatic zones according to the meridional transect (105-107 E, 44-51 N). These polygons include a wide range of territories with dry climatic conditions. This work revealed the main factors, agents, and trends of development for desertification processes in different climatic zones on the Baikal-Gobi meridional transect.

Two model key polygons were considered: 1) the Kharaa River downstream basin and the Orkhon River right feeder (territory of the Selenge and Darkhan-Uul aimags, Mongolia); 2) «Deben» (territory of the Selenginsky district of the Buryatia Republic, Russia). These polygons are situated in a semiarid climatic zone with grassland and bunchgrass steppes.

Study period. The temporal dynamics of the vegetation was estimated using archive geoportal data of the Russian Space Research Institute, Russian Academy of Sciences (IKI RAS) for the period of 2001-2014. NDVI areas were mapped with satellite images for the first half of September from 1989 to 2014.

*Landsat multispectral data.*Necessary multispectral images made by the spectroradiometer TM (Landsat-5 satellite) and spectroradiometer OLI (Landsat-8 satellite) were downloaded from the geoportal of the US Geological Survey using GloVis searchfor the selected polygons (for Deben polygon path = 132, row = 25; for Kharaagol polygon path = 132, row = 26). The spatial resolution of images was 30 meters per pixel. All images must be done with a completely cloudless sky (0 %), be of high quality (Qlty = 9), and have a sufficient level of image preparation (level L1T, orthotransformation, radiometric, and atmospheric corrections).

Images were processed with the program complex ENVI v. 4.7, which is well known as a full-functional solution for the visualization, processing, and analysis of remote sensing data.

*Digital elevation model (DEM) SRTM.*Height radar data of the DEM SRTM (Shuttle Radar Topography Mission) were downloaded from the FTP-server of the U.S. Geological Survey. To conduct relief morphometric analysis, a number of the corresponding morphometric maps were established and analyzed (along with the data of field observations): hypsometry, slopes, and aspects. Also, topographic modeling of three-dimensional images was conducted.

*Normalized Difference Vegetation Index (NDVI).*Over the last decades, remote sensing methods, especially satellites, have

provided opportunities to organize immediate vegetation monitoring. Of particular importance in the establishment of a system of remote sensing monitoring is the possibility of organizing completely automated satellite data processing. Over the last years, such technologies were actively being established and developed in IKI RAS. They allowed the creation and actualization of the archive of constant satellite observations on the territory of Russia and adjoining states for the period from 2000 until the present [2]. The Baikal Institute of Nature Management SB RAS and IKI RAS conduct collaborations in the area of using informational technologies and remote sensing methods to solve scientific problems of monitoring the state and dynamics of vegetation cover. The basis of automatized technologies established by IKI RAS is the analysis of the temporal variation of the NDVI values [3]. The NDVI is based on the analysis of differences in the chlorophyll reflection on red and near infrared zones of the electromagnetic spectrum, and it gives a numeric value for characteristics and estimates of the spatial variation of vegetation cover biophysical parameters.

While identifying vegetation species, Mongolian [4] and Buryatian [5] key to identification of plants were used.

Results and discussion

1. *Kharaagol model polygon*

According to the scheme of the landscape and the ecological district division [6] located in the central part of the Selenge River basin, the Kharaagol model polygon is situated in an area of high ecological intensity, caused by both natural and anthropogenic factors. Let us consider the key site of 19.16 km^2 situated in the northern part of the Kharaagol polygon, 3 km southeast of the Darkhan city. The biggest part of this site, located on the separated slopes of low hill terrain of the Orkhon-Kharaagol interfluve (maximal height marks are 810-870 m), has steppe caragana-cereal-fringed sagebrush (*Artemisia frigida — Leymus chinesis — Caragana microphylla*) vegetation. As geobotanical studies have shown, the small-leaved caragana *Caragana microphylla* (Pall.) Lam. dominates in the projective vegetation cover (17-20 %). Fringed sagebrush, *Artemisia frigida* Willd. is also widely spread, as well as Chinese wild rye *Leymus chinensis* (Trin.) Tzvelev, etc. Most of the land is used as pasture.

Using access to the satellite monitoring service «Vega» to monitor the vegetation condition, average NDVI curves were built for the Kharaagol key site for the first 14 years of the twenty-first century [3]. Some nonuniformity of the NDVI distribution was observed throughout the years, caused by different climate conditions. It should be pointed out that in 2007, 2008 and 2012, the NDVI values were rather high, 0.6, which is related to the higher values of temperature and moisture regime during the summer months of these years (the Service «Vega» allows to carry out the joint analysis of NDVI with meteorological parameters). The average summer value of the NDVI in 2011 was 0.45 for this site, which proves sparse vegetation during this year (Fig. 1).

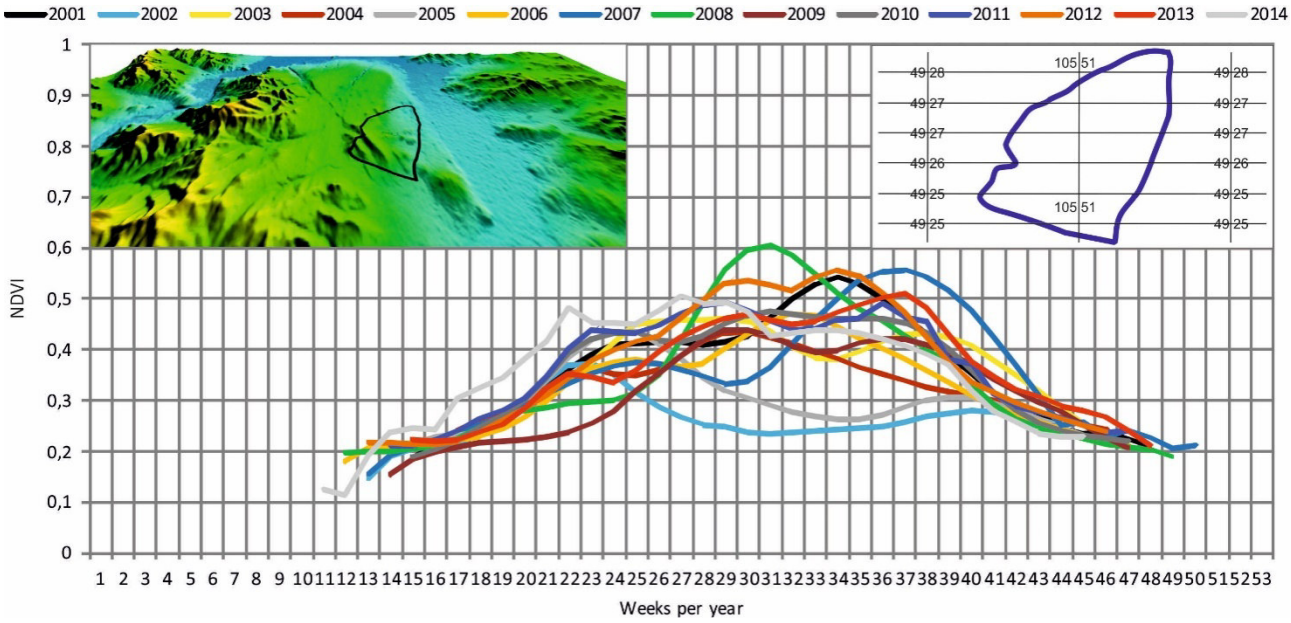

Fig. 1. Variations of averaged NDVI on 2001-2014 for the Kharaagol polygon

On this picture the upper-right inserted image is the scheme of the site; the upper left inserted image is a 3D-view on the base of DEM SRTM.

NDVI indices were calculated and visualized for the territory of the key site, based on Landsat TM and OLI multispectral space images made for September data of a 25-year difference: 1990 and 2014 (Fig. 2). While conducting field measurements GPS-tracks were prepared for the site's borders, which were later converted into vector shape files, functioning as a mask for marking the borders of the sites. The NDVI areal mapping with a 0.1 pitch was conducted only within the limits of marked closed polygons.

Comparing the NDVI images, there is a digression of vegetation conditioned mainly by a high pasture load. In September of 1990, most of the site (53 %) had 0.3-0.4 NDVI values, while in September of 2010, 86 % of its area was 0.2-0.3 and in 2014, 87 % of its area was 0.1-0.2 (Table 1).

In the field expedition studies of 2011-2014, the in-situ landscape indication of NDVI areas with different values was conducted. The natural and anthropogenic factors of the dynamics of their changes were studied.

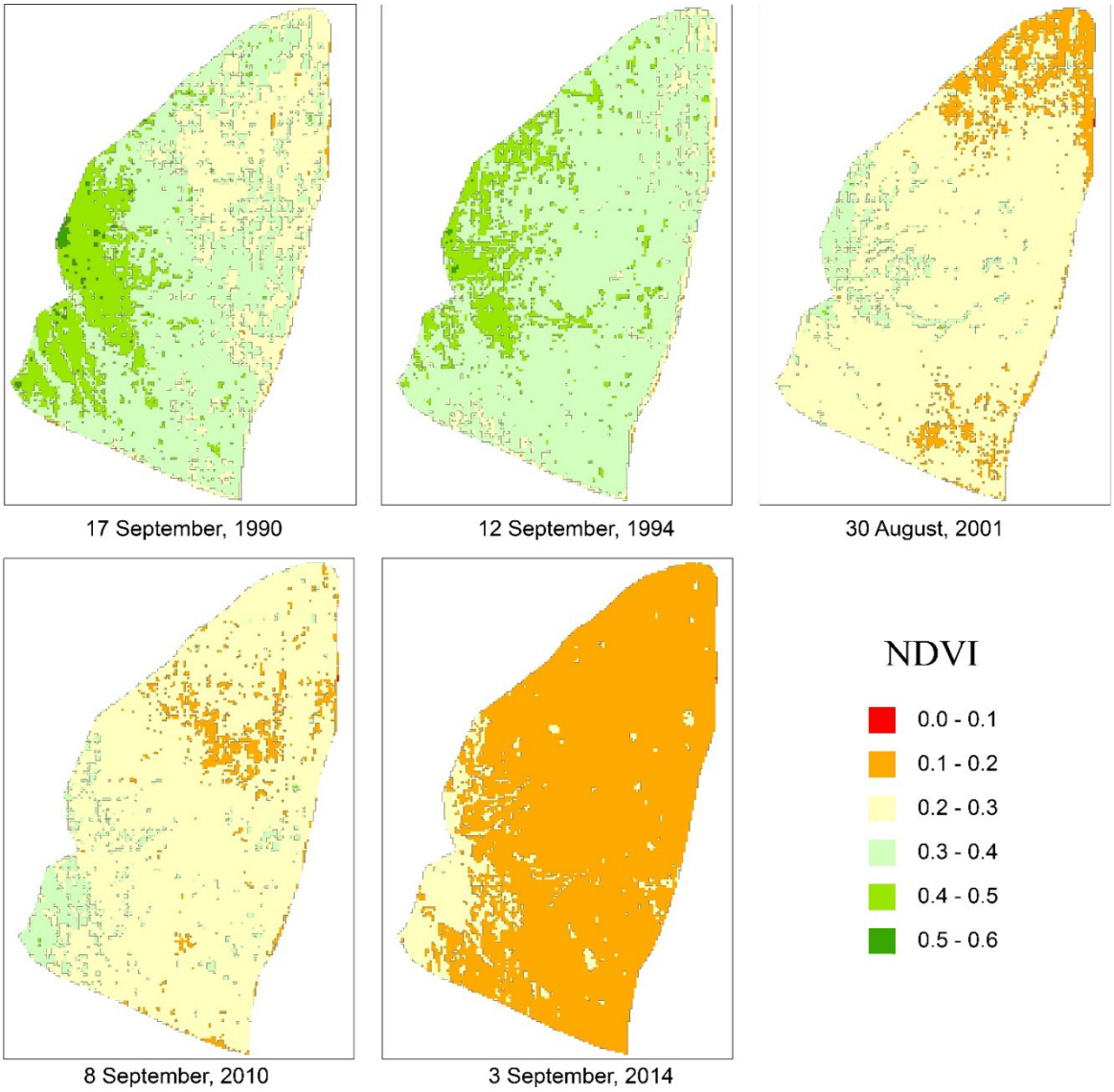

Fig. 2. Multitemporal NDVI maps for the Kharaagol polygon

The territories of plowed fields, cleared by harvests, and the areas of steppe slope pastures in the stage of high digression, caused by cattle overgrazing and characterized by a projective vegetation cover of under 50 %, correspond to NDVI values of 0.1-0.2 dated September 8, 2010, taking in 8 % of the territory (Table 1).

The most common NDVI value for September is 0.2-0.3. These are the prevailing split slope erosion denudation steppe landscapes with motley grass vegetation (*Leymus chinesis* — *Artemisia frigida* + *Potentilla acaulis* — *Caragana microphylla*). Because of cattle overgrazing, the vegetation of these landscapes experiences average digression; the value of its projective cover is mostly 65-70 %. Of the total projective vegetation cover, the small-leaved pea tree *Caragana microphylla* (Pall.) Lam. takes 17-20 %. Another 15-16 % is taken by the Chinese lyme grass *Leymus chinensis* (Trin.) Tzvelev, 12-13 % is taken by frigid sagebush *Artemisia frigida* Willd., and 9-10 % is taken by the stemless bloodroot *Potentilla acaulis* L.

Table 1. Classification on NDVI graduation for the Kharaagol polygon

NDVI	1990		1994		2001		2010		2014	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
0.0-0.1	0	0	0	0	0.00	<1	0.01	<1	0.00	<1
0.1-0.2	0.12	1	0.03	<1	2.19	11	1.58	8	16.73	87
0.2-0.3	5.44	28	1.16	6	15.52	81	16.45	86	2.41	13
0.3-0.4	10.19	53	15.37	80	1.41	7	1.11	6	0.00	<1
0.4-0.5	3.30	17	2.56	13	0.01	<1	0.01	<1	0	0
0.5-0.6	0.10	1	0.02	<1	0	0	0	0	0	0
Total	19.15	100	19.15	100	19.15	100	19.15	100	19.15	100

NDVI values of 0.3-0.4 can be observed for only 6 % of the site area (Table 2), in hollows and the far western and upper (absolute height marks of 810-870 m) parts of the slopes. The projective cover of the phytocenoses vegetation reaches 80-85 %. Among popular species, there are *Carex duriuscula* C.A. Mey., which takes 27-33 % of the projective vegetation cover, the small-leaved caragana *Caragana microphylla* (Pall.) Lam. takes 30-33 %, the Chinese lyme *Leymus chin ensis* (Trin.) Tzvelev takes 10 %, and the sage-leaf mullein *Phlomis tuberosa* L. takes 10 %.

In September 1990, some of these phytocenoses located in the western part of the area had NDVI values of 0.4-0.55. To all appearances, these phytocenoses had considerable projective cover (around 90-97 %); the highest share belonged to ling, feather grass, and mixed grasses, *Phlomis tuberose* L. in particular. It was proved by studies conducted on territories adjacent to the key site. The reason for phytocenosis digression is also cattle overgrazing.

According to the Mongolian State National Statistics Committee [7], a tendency to increase the number of farm animals was observed on the territories of Selenge and Darkhan-Uul aimags in 2000s. Express surveys conducted for arats having a household within the territories of the Kharaagol model polygon showed that nearly half of them immigrated here (to be closer to main market of animal products) with their herds in the 2000s from other periphery Mongolian aimags, the western (mostly) and Gobi.

2. *Deben model polygon*

NDVI indices were calculated and visualized for the territory of the key site «Deben», based on Landsat TM and OLI multispectral space images made for September data of a 26-year difference: 1989 and 2014 (Fig. 2).

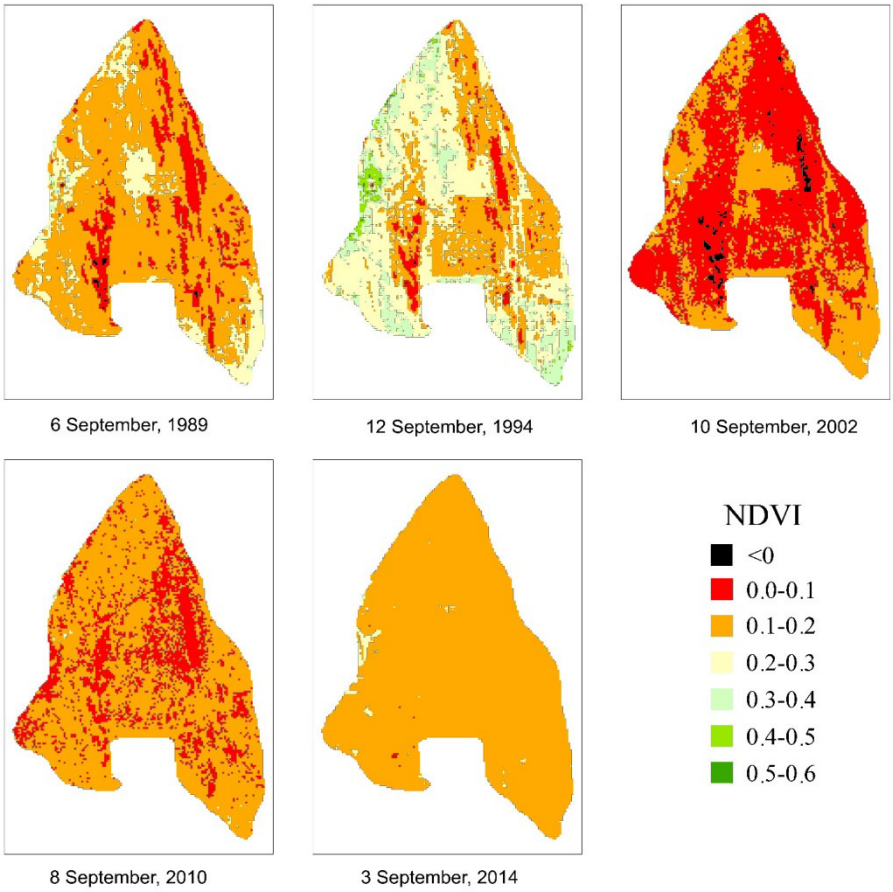

Fig. 2. Multitemporal NDVI maps for the Deben polygon

Among the desertification types discovered by FAO-UNEP [8] on the greater part of the Selenga River basin, especially in its Mongolian part, the vegetation cover degradation is the most widely spread (Fig. 2, Table 2). It is revealed in structural changes of the steppe, forest steppe, and pasture phytocenosis, the successions of their species by synanthropic ones, and decreased projective cover and grass height [9].

In September of 1989, most of the site (70.46 %) had 0.1-0.2 NDVI values, while in September of 2014, 98.65 % of its area was 0.1-0.2 (Table 2).

Table 2. Classification on NDVI graduation for the Deben polygon

NDVI	1989		1994		2002		2010		2014	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
<0	0.03	0.24	0.00	0.03	0.1998	1.38	0	0	0	0
0.0-0.1	2.03	14.03	0.75	5.22	8.59	59.48	3.80	26.33	0.01	0.09
0.1-0.2	10.18	70.46	5.08	35.16	5.57	38.59	10.61	73.46	14.25	98.65
0.2-0.3	2.13	14.75	6.46	44.74	0.08	0.53	0.03	0.19	0.18	1.24
0.3-0.4	0.07	0.50	1.88	13.05	0.00	0.02	0.00	0.02	0.00	0.02
0.4-0.5	0.00	0.02	0.24	1.69	0	0	0	0	0	0
0.5-0.6	0	0	0.02	0.11	0	0	0	0	0	0
Total	14.45	100.00	14.45	100.00	14.45	100.00	14.45	100.00	14.45	100.00

Conclusion

The performed studies for different channels of optical range, using methods based on the consideration of differences in spectral reflection, together with field in-situ studies, prove that the degradation of the vegetation cover is increasing.

Remote sensing methods, based on the analysis of spatial and temporal differentiation of biophysical vegetation parameters, quickly allow a determination of areas of ecological intensity conditioned by the degradation of vegetation cover and desertification.

Cattle overgrazing is observed on the studied areas. It conditions overload for pastures and leads to the digression of their vegetation cover. Therefore, livestock farmers and other land users have to use pasture rationally, changing grazing areas from time to time and thus regulating the grazing rotation.

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References

1. Gunin P.D., Miklyaeva I.M., Bazha S.N., Slemnev N.N., Cherdonova V.A. Peculiarities of degradation and desertification of the herbal communities of forest steppe and steppe ecosystems of Southern Transbaikalia. *Aridnye jekosistemy.* 2003, Vol. 9, No. 19-20, pp. 7-21. *(In Russian).*

2. Lupyan E.A., Mazurov A.A., Nazirov R.R., Proshin A.A., Flitman E.V. Method of design of automated systems of collection, delivery, and storage of satellite data for solution of scientific and applied tasks. *Sovremennye problemy distancionnogo zondirovanija Zemli iz kosmosa.* 2004, Vol. 1, pp. 81-88. *(In Russian).*

3. Lupyan E.A., Savin I.Yu., Bartalev S.A., Tolpin V.A., Balashov I.V., Plotnikov D.E. Satellite service «Vega» for monitoring of vegetation conditions. *Sovremennye problemy distancionnogo zondirovanija Zemli iz kosmosa.* 2011, Vol. 8, No. 1, pp. 190-198. *(In Russian).*

4. Grubov V.I. Key to Identification of Vascular Plants of Mongolia. [Opredelitel' sosudistyh rastenij Mongolii.]. Leningrad: Nauka. 1982. *(In Russian).*

5. Anenkhonov O.A., Pykhalova T.D., Osipov K.I., Badmaeva N.K., Munkueva M.S., Krivobokov L.V., Namzalov B.B., Sekulich I.R., Sutkin A.V., Tubanova D.Ya., Tubshinova D.B. Key to Identification of the Plants in Buryatia. [Opredelitel' rastenij Burjatii.]. Ulan-Ude: Buryat Science Centre. 2001. *(In Russian).*

6. Gunin P.D., Vostokova E.A. Landscape Ecology. [Landshaftnaja jekologija]. Moscow: Bioinformservis. 2000. *(In Russian).*

7. Mongolian Statistical Yearbook 2009. Ulaanbaatar: Mongolian National Statistical Office, 2010.

8. Provisional Methodology for Desertification Assessment and Mapping. — Rome: FAO/UNEP, 1981.

9. Miklyaeva I.M., Gunin P.D., Slemnev N.N., Bazha S.N., Fakkhire A. Violated vegetation of steppe ecosystems. *Aridnye jekosistemy.* 2004, Vol. 10, No. 24-25, pp. 35-46. *(In Russian).*