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SATELLITE-BASED MONITORING OF TERRITORY USING VEGETATION INDICES AND THEIR CORRELATION WITH GROUND DATA

SAGYNBAY KALDYBAYEV, NURLAN BEKMUKHAMEDOV, KAZBEK SMAILOV, KENZHE ERZHANOVA, NIET ABDIRAHYMOV

Kazakh National Agrarian University, Almaty, Republic of Kazakhstan

ABSTRACT

This article estimates pastures of Kazakhstan in terms of degradation processes of semidesert and dry steppe zones in various seasons using GIS technologies. Ground surveys and space data of medium and low resolution have been interrelated. Variations of vegetation index (NDVI) have been analyzed at all considered test sites. Space monitoring of semidesert and dry steppe zones of Kazakhstan by means of vegetation indices and their correlation with ground data make it possible to evaluate current status of pasture degradation, to detect sources of highly degraded pastures, and to perform their monitoring. An interval of vegetation period selected for the analysis allows to correlate maximum and minimum NDVI with maximum and minimum values of green biomass, that is, with pasture degradation.

Keywords: *GIS technology, Earth remote sensing (ERS), Vegetation index, Satellite estimate, Monitoring, Pasture degradation*.

1. INTRODUCTION

At the present stage of development of space technologies, satellite information is used for monitoring of soil degradation [1]. Numerous approaches are proposed based on the indices which are linear fractional combinations of spectral channels on visible, near IR and IR ranges of spectrum [2]. Various indices allowing to perform monitoring are proposed for various natural conditions [3]. However, unified universal index, suitable for all circumstances and any territories, is unavailable [4, 5].

Despite the increasing number of methods to recognize ground covering [6], development of accurate maps of measurements for regional land management, monitoring of natural vegetation is still a complicated issue [7]. Global generalization (compilations) of regional projects on analysis of modification in ground covering reveals the issue of their noncompatibility and evidences necessity to improve mapping of vegetation covering and its variations as well as understanding the reasons of such transformations [8]. Herewith, the information support of the developed methods of satellite monitoring should be based on ground observations and data of spectral and physical properties and features of the considered objects [9].

The novelty of this work is that the methodological approach presented in the article has revealed that the data from Modis satellite sensors are suitable for development of soil degradation maps of regional scale. The data from Landsat and Sentinel satellites are more suitable for analysis of local degradation.

This work is aimed at analysis of degradation indicators and development of satellite-based monitoring of pasture in semidesert and dry steppe zones of Kazakhstan.

2. METHODS

The studies of pasture degradation in semidesert and dry steppe zones of Kazakhstan using data of field tests and digital technologies were planned on cardinally new procedural basis. All experimental stages were based on local properties of degraded pastures. In this study cartographic method was the leading method of representation of pastures in their interrelation with other components of natural and agricultural systems. High attention was paid to the deciphering of data of remote sensing, which allowed to solve quickly the formulated problems on precise detection of peculiar objects with appropriate degradations; on establishment and adjustment of boundaries and peculiarities of their state. Regarding evaluation of

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pastures, application of distant sensing and field tests made it possible to evaluate real state and possibilities of pasture recovery.

Field tests. The physical (soil) and biological (plants) indicators were analyzed at each basic site (selected by Terra Modis satellite images for the years 2017-2019). The data were acquired at the basic sites in terms of four stages of pasture degradation: 1 - weak, 2 - medium, 3 - strong, and 4 – degradation.

List of biological indicators:

- name of vegetation community (background);
- composition of species (at 1 $m^2 \times 4$) and botanical composition of plants (%);
- poisonous and non-eatable plants (% in harvest),
- projective covering of soil by plants (%);
- pasture yield (cwt/ha at natural moisture content);
- fodder quality (fodder units);
- grazing availability (yes, no).

The form of geobotanical description and anthropogenic modification of the background community was compiled including digital biological indicators. The distance between the boundaries of vegetation contours (km) of various pasture degradation was measured and recorded.

The studies related with biological indicator were carried out according to the following validated procedures [10, 11].

The studies of physical (soil) indicators were based on conventional methods [12]. Soil map was developed by contouring using GIS technologies.

Full-profile soil cross sections were determined, their profiles were described, and soil samples were taken by genetic horizons. At the sites of various degradation degrees, soil samples were taken from the depths of 0-10, 10-20, and 20-30 cm. Soil analyses and evaluation of fodder nutrition were carried out in respective certified laboratories.

The field studies of pasture degradation degree in semidesert and dry steppe zones were performed along the route passing across East Kazakhstan, Pavlodar, Karaganda, Kustanay, Akmolinsk oblasts at basic sites [13, 14].

Studies by ERS data. Determination of pasture degradation using the ERS data.

a) *Input data.* GIS project is created on the basis of all available cartographic material for the considered territory, supplemented by thematic maps obtained by processing of satellite data.

Cartographic material. Raster data include cartographic material and satellite images. Thus, database contains topographic maps at 1:200,000 and 1:100,000 scales. Thematic maps include soil map, hydrogeological map of forage lands. The map of forage lands at 1:1000,000 scale was used as the basis.

Geobotanical map was used as a corrective basis for the vegetation cover. Upon deciphering of satellite images of medium resolution, the most suitable for practical application were geobotanical maps of fine scale. The territory of demonstration sites should be covered with large scale maps of forage lands. All data were given in a single geographical projection.

ERS data.

1. The satellite images were selected from the catalog for the vegetation period. The data from satellites of medium resolution (Landsat 8, Sentinel 2, Modis TERRA) were used for the purposes of ground-truth observations (determination of degradation degree and detailed classification of test sites with subsequent verification of ground and satellite data).

Vector data. The thematic layers contained digitized data of thematic maps with required attributive information. The data of field studies were included in the form test site objects from GPS receiver and supplemented by attributive information from field logs and forms.

Analysis of Interaction between Ground and Satellite Data on Test Sites. The aforementioned spectral indices, surface temperatures, as well as the differences between different dates of image acquisition were computed for each considered scene. Preliminary processing of satellite data and calculation of the required indices were performed using Exelis ENVI 5.2 software. Cartographic processing was performed using ESRI ArcGIS 10.2S. Statistic processing of ground and satellite data was performed using StatSOFT STATISTICA 12.0.

Standard deviation, SD, “s” or "σ" is the variable showing how much the observation data deviate from the expected value. The lower is the SD, the closer are the data of specific observation to selection average (i.e. expected value).

Processing of satellite images to detect main classes of surface. The computation method is based on two spectral indices (LDI-NDVI, LDI-TCW) [15] developed for evaluation of soil degradation. While considered separately, these indices under conditions of Kazakhstan pastures are not characterized by high information content. The computation method of degradation centers by satellite images, based on these indices, considers for such parameters as character and dynamics of vegetation covering (NDVI), surface moisture content (TCW), and brightness of surface in red channel of satellite image, where open soils are characterized by the highest brightness properties.

Analysis of this computation method at various territories demonstrates that for Landsat 8, Sentinel 2, Modis TERRA satellite data there existed certain range of index determining sites with constantly degraded soil covering, which were detected at the images irrespective of time or year of image acquisition. At the same time, a range of index was highlighted, which described seasonal variations of soil covering, for instance, drying out of bank and bottom of temporary pools [16, 17].

Degradation of soil and vegetation covering, decrease in plant biomass and total projective cover, baring of soil cover occur as a consequence of natural or anthropogenic factors [18-22]. The degradation was determined by special indices of spectral brightness developed with consideration for wavelength of visible and infrared spectra, at which this class had minimum and maximum absorption. The main satellite indices applied for the computations are as follows:

- NDVI (normalized difference vegetation index)
- Bare Soil Index.

3. RESULTS

The analysis of vegetation indices at 12 considered test sites of semidesert and dry steppe areas performed from May 20 to June 20, 2019 demonstrated the following:

1) There were no explicit features of pasture degradation. The degradation sites (IV degree) in terms of the indicators were similar to III degree (strong degradation).

2) In all cases, degradation of the considered pasture sites of semidesert and dry steppe zones was determined by:

- modification (deterioration) of pasture vegetation, when the type of pasture background was absolutely different in comparison with a site of III degree of degradation;
- yield of background pasture forage differed from that of strongly degraded site by 5 cwt/ha and higher.

The fodder nutrition was in direct correlation with the pasture states (Table 1).

Table 1: Fodder nutrition at natural moisture content at basic sites (per 100 kg of fodder), fodder units

Names of basic sites	Degradation degree			
	IV - degradation	III - strong	II - moderate	I - weak
Gulshat	18	20	22	22
Akshatau	-	20	22	24
Aksu-Agaly	-	21	24	24
Atasu	-	20	23	25
Zhalgiztal	-	22	24	28
Furmanova	-	27	27	28
Tasty-Taldy	-	20	23	25
Prirechnaya	-	23	23	28
Kalkaman	-	26	26	28
Akku	-	23	23	29
Shar	-	26	27	26
Zhangiztobe	-	22	26	28

It follows that at a site with weak pasture degradation, the fodder nutrition was higher in comparison with a site with strong degradation, which was logical. Rather low yield of pastures was observed, which was determined by insufficient temperature of air and soil at sufficient soil moisture content.

Database structure.

The developed database contains geospatial data and data in the form of tables and files, which can be requested and which are available from various web servers. The database guarantees the data integrity and availability for several servers simultaneously (for instance, for visualization and downloading).

At the Database level (Fig. 1), it is possible to connect and to manage several spatial databases in terms of thematic properties so that to provide them for logical level for visualization of service processing. Therefore, it is possible to support spatial functions and indices, which provides better efficiency for selection and processing of spatial data. It is not obligatory to store various sets of data in one central base, since the system is comprised of modules, and the level logics can operate with various data sources. The data level is managed by PostgreSQL database with PostGIS spatial add-on. The control system supports import and export of all main spatial formats, such as Shapefile, GeoTiff, GeoJSON, the well-known text (WKT), etc. PostGIS supports GiST based on R-Tree of spatial indices and functions for analysis of processing of GIS objects.

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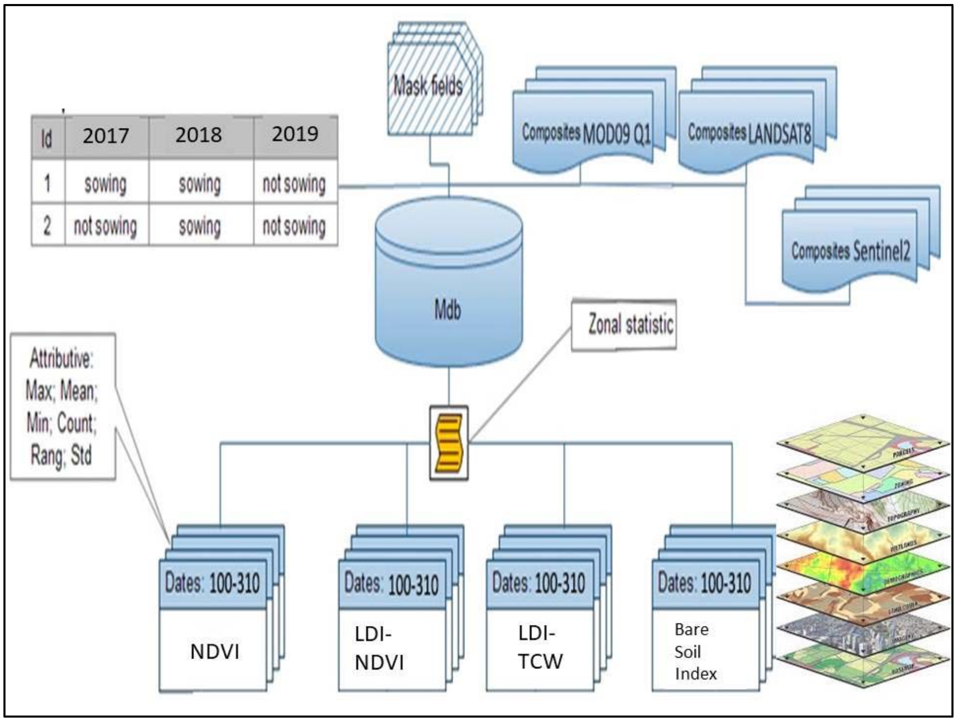

Figure 1: Structure of satellite database for monitoring of pasture degradation.

In order to provide the main requirements to loading spatial data and their preparation, the following stages were implemented:

– definition of spatial data list, development of structure of geodatabase (overview of reference books, codifications, rules of identification codes of spatial data);

– optimization, spatial and attributive indexation;

– unified cartographic projection;

– matching map legends, scales, gradations;

– single level of generalization.

All requirements to representation of database structure were fulfilled except for those violating integrity of database. The classes of spatial objects (feature class), repeated with identical attributive information but for different dates, were presented in feature class dataset, however, they could be absent in description.

The Pasture degradation feature class dataset contained several layers and was regularly updated, only the date and satellite passing were different. The data of satellite monitoring are summarized in Table 2.

Table 2: Published ERS data

Types of parametric deciphering regarding ERS	Name of output raster materials	Alias
NDVI (normalized difference vegetation index)	154-122NDVI	LC150030154-122NDVI
	177-161NDVI	LC151030177-161NDVI
	193-177NDVI	LC151030193-177NDVI
	191-159NDVI	LC153030191-159NDVI
LDI-NDVI	154-122 LDI-NDVI	LDI 150030154-122 NDVI
	177-161 LDI-NDVI	LDI 151030177-161 NDVI
	193-177 LDI-NDVI	LDI 151030193-177 NDVI
	191-159 LDI-NDVI	LDI 153030191-159 NDVI
LDI-TCW	154-122 LDI-TCW	LDI 150030154-122 TCW
	177-161 LDI-TCW	LDI 151030177-161 TCW

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	193-177 LDI-TCW	LDI 151030193-177 TCW
	191-159 LDI-TCW	LDI 153030191-159 TCW

While the satellite images and data of ground observations were supplied, the geodatabase was supplemented.

Selection of spatial resolution upon generation of maps was determined by specific tasks of monitoring. This could be maps of various scales covering the overall territory of republic, certain oblasts or districts.

Selection of time intervals was also determined by specific task. Periodicity of database updating was evaluated on the basis of efficiency of image acquisition from Sentinel 1;2, Landsat-8 and time for processing of this information in GIS.

4. DISCUSSION

The information system of steady management of pasture resources by distance sensing was developed on the basis of satellite parameters characterizing vegetation state, detection of pasture sites with low projective cover and efficiency, determination of observation time and prediction. Starting form vegetation beginning and to blooming, the main factor affecting spectral properties of vegetation was increase in biomass. Herewith, the coefficient of spectral reflection decreased in the red spectrum range and increased in the near IR range, which led to variations in the vegetation index. These features were peculiar for late spring and early summer observations, when intensive growth of ephemers and empheroids took place as well as suckering of perennial grass and shrub vegetation. Upon drying of above ground biomass, the vegetation index varied in the reverse order. Table 7 shows equations and properties of various vegetation indices intended both for evaluation of mixed soil–plant signal and for complete soil covering by vegetation.

The vegetation index is aimed at creation of correct system of linear weighing: index value - vegetation parameters. The vegetation parameters are in general either the amount of green biomass, or the fraction of projective leaf cover of soil.

In our studies the pasture degradation was evaluated by maximum NDVI obtained by Landsat 8 data for the year 2019. Thematic processing of the satellite data was performed using Arc Gis 10.5 software.

The difference of green biomass at tests sites of Aksu-Ayuly OPP was 80-83%, the yield amounted to 13.6 cwt/ha, and at Akshchetau OPP, the difference of green biomass was 65-70%, the yield amounted to 13.4 cwt/ha. NDVI in May was 0.27 and 0.23 for Aksu-Ayuly and for Akshatau, respectively (Figs 2, 3, 4). Then decrease in vegetation was observed until late June–early July, with subsequent sharp increase.

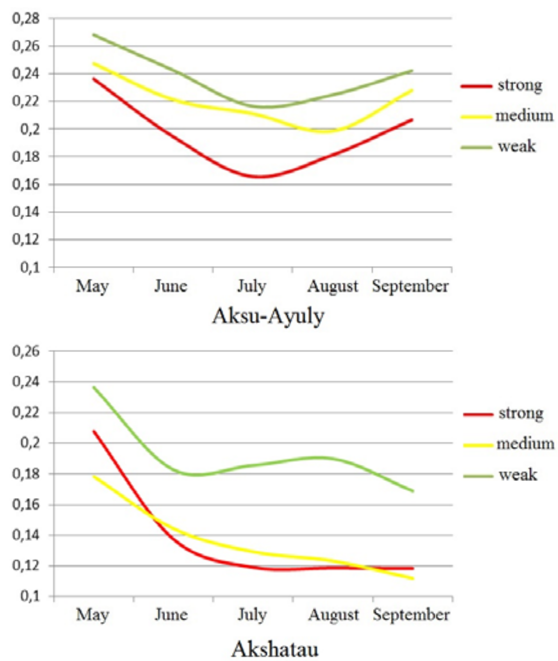

Fig. 2. NDVI in terms of degradation of soil plant cover.

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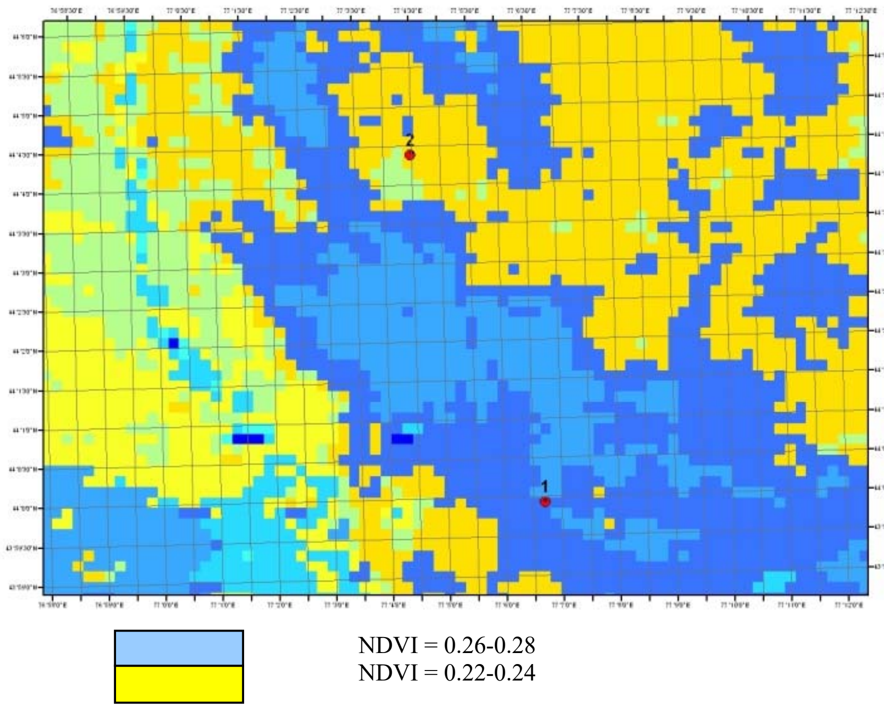

Figure 3: NDVI for the end of May, 2019 plotted by image from Landsat 8 satellite, Aksu-Ayuly test site

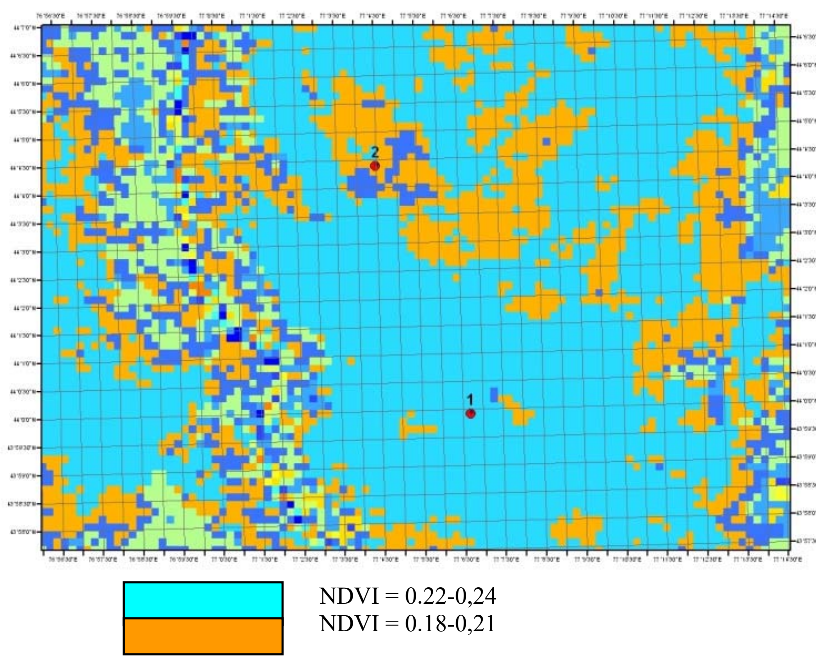

Figure 4: NDVI for the end of May, 2019 plotted by image from Landsat 8 satellite, Akshatau test site.

On the basis of field tests, the analysis of interaction was carried out between the ground parameters and indices of spectral brightness ratios calculated for satellite sensors: TERRA/MODIS, Sentinel 2, Landsat. At each test site, the contours by degradation degree were determined on the basis of ground data. The contours of various degradation degree were plotted on the basis of Landsat data. For each contour, the degradation was evaluated by means of NDVI (Fig. 5).

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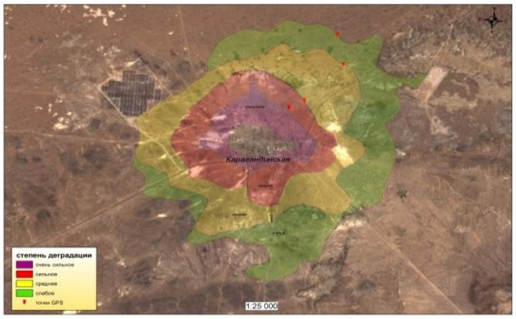
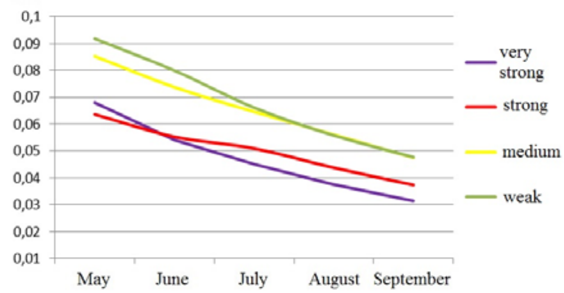
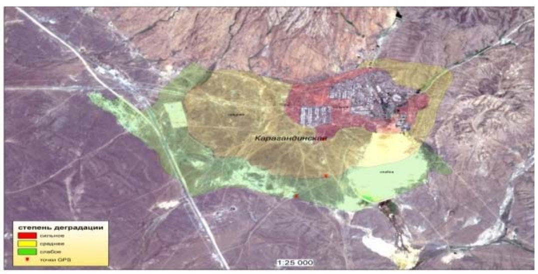
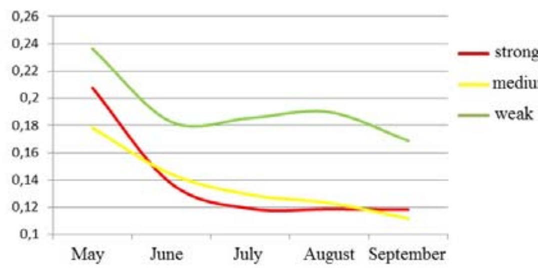

Contour positions of test site 1 – Gulshat: at various degradation degrees



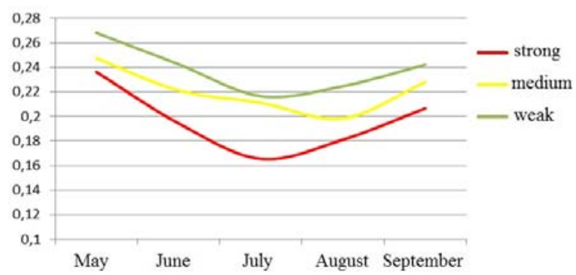
NDVI of site 1 from May to September, 2019 based on Landsat 8 satellite images


Contour positions of test site 2 – Akshatau: at various degradation degrees

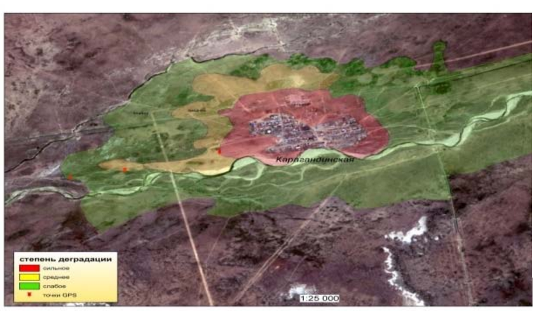


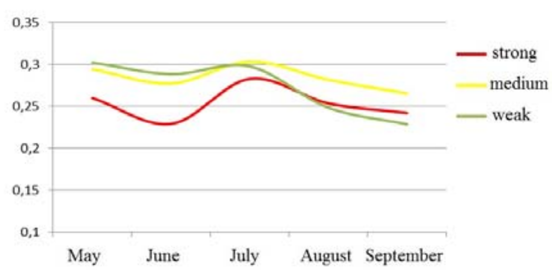
NDVI of site 2 from May to September, 2019 based on Landsat 8 satellite images


Contour positions of test site 3 – Aksu-Ayuly: at various degradation degrees



NDVI of site 3 from May to September, 2019 based on Landsat 8 satellite images


Contour positions of test site 4 – Atasu: at various degradation degrees



NDVI of site 4 from May to September, 2019 based on Landsat 8 satellite images

Figure 5: Contour positions, NDVI at various degradation degrees.

Analysis of NDVI by the contours with various degradation degrees makes it possible to state that the degradation was not homogeneous. The degree of anthropogenic impact depends mainly on the degree of pasture utilization, that is, grazing, climate, and vegetation community. At certain test

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sites, for instance, test site 4, transition of contour with weak degradation to strong degradation was observed. The transition was detected in the second decade of August. This could be attributed to higher load on pastures (overgrazing).

In the scope of the studies, information content of thematic classes of Sentinel 2 data was analyzed for various spectral channels. The obtained results would allow to reject some excessive spectral indicators before classification of overall image. The analysis can be based on several methods.

On the basis of information content of thematic classes of Sentinel 2 data, the degradation was evaluated for various vegetation periods at the considered test sites (Figs. 6, 7, 8).

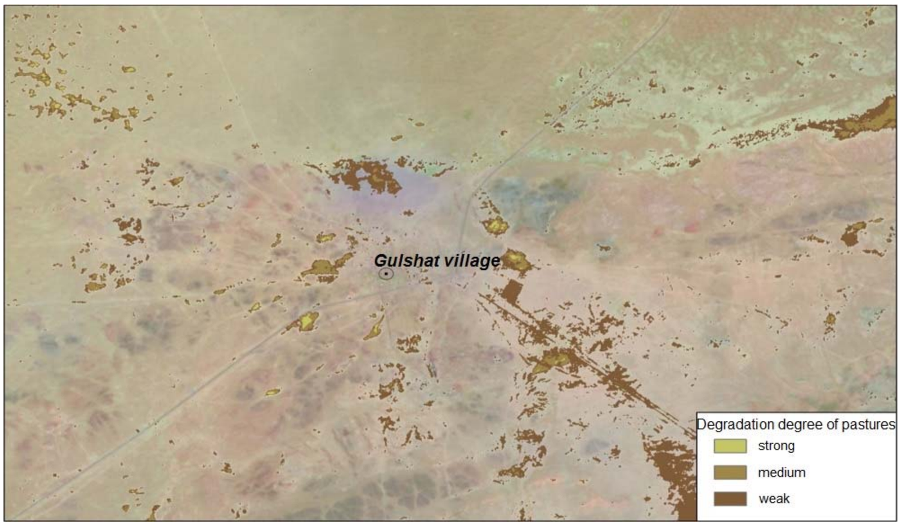

Figure 6: Satellite estimation of degradation degree of natural vegetation in the vicinity of Gulshat village based on Sentinel-2 image, May 29, 2019

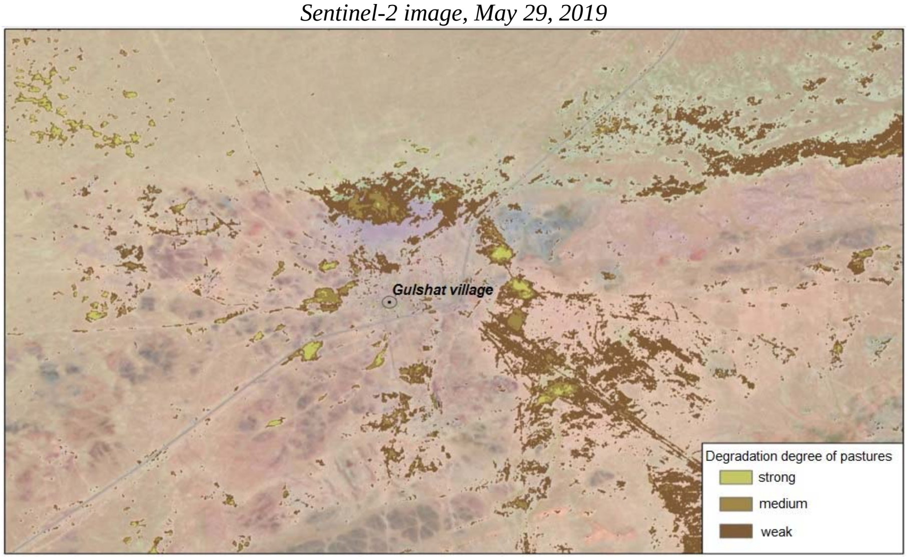

Figure 7: Satellite estimation of degradation degree of natural vegetation in the vicinity of Gulshat village based on Sentinel-2 image, June 18, 2019

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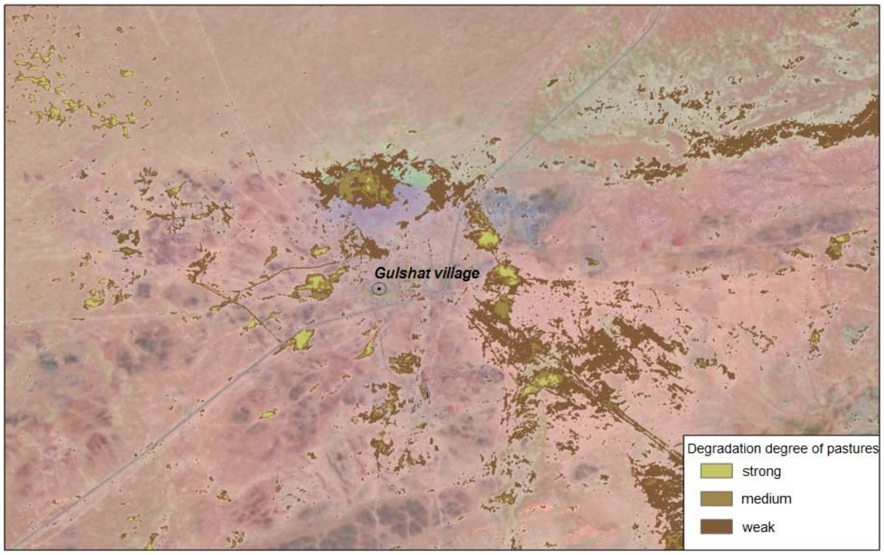

Figure 8: Satellite estimation of degradation degree of natural vegetation in the vicinity of Gulshat village based on Sentinel-2 image, July 18, 2019

Analysis of Interaction between Ground and Satellite Data on Tests Sites

Preliminary processing of satellite data and calculation of required indices were performed using Exelis ENVI 5.2 software. Cartographic processing was carried out using ESRI ArcGIS 10.2. Statistic processing of ground and satellite data was carried out using StatSOFT STATISTICA 12.0.

Standard deviation, SD, "s" or "σ" is the variable showing how much the observation data deviate from the expected value. The lower is the SD, the closer are the data of specific observation to selection average (i.e. expected value).

The standard deviation in general was not high for all measured parameters except for biomass. The scatter in this case was related with heterogeneity of vegetation cover on degraded sites.

In addition to standard deviation, an important characteristic of data statistical distribution is their normality. Standard normal distribution is the normal distribution with mathematical expectance 0 and standard distribution 1. Normality of selection was evaluated for each considered parameter. Figure 9 exemplifies normal distribution for biomass parameter. The data in the range of normal distribution can be analyzed by standard statistic methods.

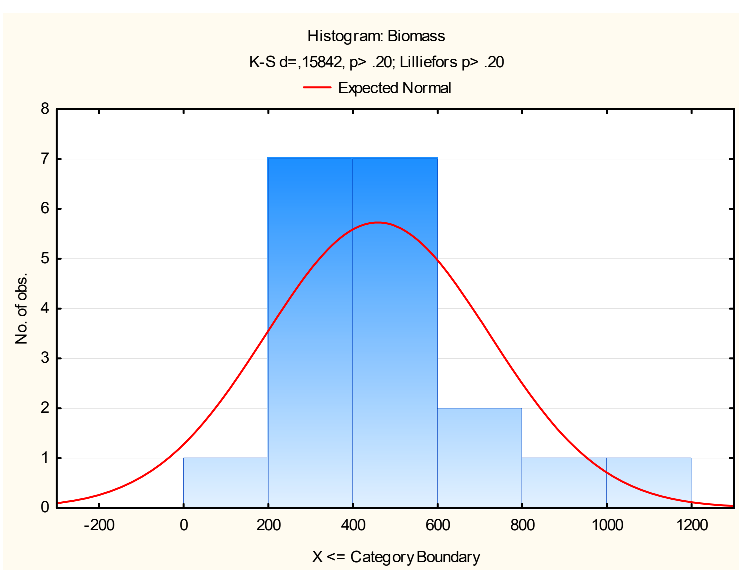

Figure 9: Normal distribution of biomass at test sites

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Being ascertained that the ground and satellite data are statistically reliable and subject to normal distribution, it is possible to determine their correlation degree. Several methods were applied to calculate the correlations.

Pearson's correlation coefficient is the standard correlation coefficient characterizing existence of linear dependence between two values/selections.

Spearman's rank correlation coefficient is the measure of linear relationship between random values. The Spearman's statistics assume that the considered variables are measured at least on ordinal scale; in other words, the individual observations are ranked.

One more method to establish correlations among several data groups is Gamma coefficient, which is preferred in the cases when data contain numerous coinciding values.

Table 3 summarizes the main parameters of biophysical state of vegetation cover and spectral indices with the highest correlation with them.

Table 3: Indices and their correlation with ground data for parametric deciphering of performances of plant cover

Indices	Biomass	Total projective cover
NDVI	0.7	
LDI-NDVI	0.72	
LDI-TCW		0.7

5. CONCLUSION

Variations of NDVI have been analyzed in the territories of all considered test sites. Space and time variations of NDVI evidence the occurring modifications in pasture plant cover, in particular, the peak and decrease in vegetation of plants. These data can be used for oriented deciphering of plant associations not only in Kazakhstan but also in other locations.

The authors believe that the extended time interval selected for the analysis allows to correlate maximum and minimum NDVI with maximum and minimum values of green biomass, that is, with pasture degradation.

The vegetation indices and their correlation with ground data make it possible to evaluate current status of pasture degradation.

The methodological and methodic principles developed as a result of the study and the data obtained on their basis have formed the background for building a system of space monitoring of the state of pasture areas in the semidesert and dry steppe zones of the Republic of Kazakhstan.

As the prospects for using the results obtained, the authors consider it necessary to conduct research work on predicting the deterioration of the soil cover in certain territories of Kazakhstan on the basis of the proposed monitoring system.

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