Assessment of NDVI and SAVI Vegetation Indices Potential to Monitor Grazing Impact in a Rangeland Ecosystem

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Abstract
The vegetation changes of semi-desert and desert landscapes are temporally and spatially heterogeneous. Vegetation indices derived from remotely sensed data have long been proposed as a source of information for predicting green biomass levels. This research aimed to assess vegetation status via remote sensing techniques using Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI) in semi-desert and desert environments. The feasibility of applying such techniques is tested for assessing grazing impact in Forish district of Uzbekistan. Time-series of ecological indicators of land degradation that are collected synoptically from local to global spatial scales can be derived from the 43-year and continuing Landsat satellite archive. Consequently, this study was conducted in the Forish rangeland ecosystem using a time-series of standardized Landsat imagery for the period 2010 to 2015. Two common vegetation indices derived from Landsat Surface Reflectance (LSR) imagery. Five images, one image for each year were used for the analysis. The research had the objectives to characterize and map the historical trends of a remotely-sensed index of vegetation response, a correlate of vegetation cover or phytomass, and field geobotanical monitoring results and define the appropriate values for four degradation levels (weak, average, strong and very strong). Those values were applied for 2010-2015 years period to define degradation level in order to monitor grazing impact in the study area.

1. Introduction

Rangelands are lands that are not: farmed, dense forest, entirely barren, or covered with solid rock, concrete, or ice. Rangelands are grasslands, shrublands, woodlands, and deserts. Rangelands are usually characterized by limited precipitation, often sparse vegetation, sharp climatic extremes, highly variable soils, frequent salinity, and diverse topography. Of the earth's total land surface, 47% is rangeland (University of Idaho, 2009). Area of rangelands of the five Central Asian states accounts for about 80% of their territory and serve as the main source of forage for livestock (GL-CRSP, 2000). Rangelands in the region occupy a total land area of 286 Mha, of which 25.3% are deserts (less than 150mm rainfall) and 74.7% is steppe (over 150mm rainfall) (CASCANet, 2006).

The grassland-based livestock production systems of Central Asia use rangelands that are only suitable for grazing due to a rainfall insufficient for sustainable rainfed crop production (FAO, 2007). Agricultural cooperative (shirkat) - an independent economic entity with a legal personality based on a mutual basis and mostly family (collective) contract, a voluntary association of citizens for the production of marketable agricultural products. (Law of the Republic of Uzbekistan, 1998). Nowadays the total land area of Uzbekistan is 44410.3 thousand hectares, hayfields and pastures 20750.4 thousand hectares, which is 46.7 percent of the total land area (Goskomzemgeodescadastre, 2012).

The livestock sector is one of dynamically developing agricultural sectors of Uzbekistan, accounting for 46.3%1 of the gross national agricultural output. The bulk of livestock output is produced by small household (dehkan) farms with an average size of 0.15 hectares (ha), which is the key specific feature of the sector. Livestock production in dehkan farms plays a significant social role, because it is the important source of income and food for rural families (Yusupov et al., 2010). There are more than 14 million livestock, including 10141.3 thousand cattle, 16187.1 thousand sheep and goats, 195192 horses in Uzbekistan. Based on this, we can see that 1.44 hectares of hayfields and pastures correspond to each livestock. According to statutory regulations, it is indicated that one livestock must be coincided with 1 ha of pasture in extensive technologies. The number of livestock increased, but the pasture lands decreased by 11.6 %, from 1990 till 2012 (Teshaboyev and Sharipov, 2013).

To stimulate grazing of flocks in remote grasslands rather than nearby villages it is suggested to establish a pasture fund to be supported from land leasing payments as well as income from environmental services such as carbon sequestration (Rosales and Livinets, 2005, FAO, 2006).

Efficient use of pasture resources, reclamation and environmental problems should be solved by using advanced technology and efficient methods are one of the most important issues. Fortunately, scientists around the world started long ago to look at the problem of land degradation and have developed assessment and monitoring methods. Therefore assessment methods have been developed to determine the status of the land, extent and impact of land degradation and to help designing possible conservation activities. Accurate and relevant assessment methods of land degradation in drylands with a flexible scale combining socio-economic, institutional, and biophysical aspects and driving forces are needed to plan actions and investments to reverse land degradation, improve socio-economic livelihoods, and conserve dryland ecosystems and its unique biological diversity (Snel and Bot, 2003). Ostir et al., (2003) pointed out that remote sensing has developed as an important tool for assessment and monitoring of vegetation, erosion, and desertification. It can provide calibrated, quantitative, repeatable and cost-effective information for large areas and can be related to the field data (Jafari et al., 2008). Remote sensing has been used successfully utilised in land degradation assessment and monitoring over a range of spatial and temporal scales (Jafari et al., 2008).

Remote sensing offers unique opportunities to monitor grazing landscape processes, reflected in a large number of studies on land use/land cover change (Kiage et al., 2007 and Mambo et al., 2007). Its techniques have long been applied for the quantitative and qualitative evaluation of vegetation in semiarid ecosystems. Visible and near-infrared (NIR) multispectral images are the most useful data to examine vegetation patterns and corresponding ecological processes at regional and global scales. Vegetation indices (VI) (Elvidge and Che, 1995) derived from remotely sensed data have frequently been proposed as a method for predicting green biomass.

In remote sensing applications, VI's play a significant role for qualitatively and quantitatively evaluating vegetation cover by contrasting intense chlorophyll pigment absorption in the red against the high reflectivity of plant materials in the NIR (Tucker, 1979). Studies on the use of remote sensing for assessing the impact of livestock grazing on vegetation cover and land degradation in arid and semi-arid areas are numerous (Graetz and Gentle, 1982, Bastin et al., 1993a, 1993b, Pickup et al., 1993; Pickup and Chewing, 1994 and Pickup, 1995). In this research, we apply and evaluate well-used VIs from satellite data for detecting grazing impacts in a semi-desert and desert environment and compare it with ground measurements of vegetation.

Vegetation indices among other methods have been reliable in monitoring vegetation change (Glenn et al., 2008). One of the other most widely used indices for vegetation monitoring is the NDVI because the vegetation differential absorbs visible incident solar radiation and reflects much of the near infra-red (NIR). To reduce the impact to the NDVI from the soil variations in lower vegetation cover areas, Huete (1988) proposed a soil-adjusted vegetation index (SAVI) by introducing a correction factor L (Yang et al., 2008). The SAVI was found to be an important step toward the establishment of simple "global" model that can describe dynamic soil-vegetation systems from remotely sensed data (Huete, 1988).

2. Materials and Methods

The research area (1480 km^2) comprehends the territory of the shirkats “Bogdon”, “Orolov”, “Mustakillik”, “Narvon” the forest agency in Forish district. It is shown in Figure 1 by marking with a red rectangle. It consists of different ecosystems, including a plain with steppe and semi-desert vegetation (about 20-30 kilometres broad), where four villages and about 30 shirkat farms are situated, the foothills of the mountains with mainly steppe vegetation, where about 25 villages are situated along the mountain streams and the Nuratau mountain range in the South, mostly under the administration of the forest agency (Fischer-Zujkov et al., 2011). In this research Landsat TM/ETM+ Surface Reflectance imageries, which represent the wet season (May-June) of 2010 for correlating to the field monitoring results, and dry season (August–September) of the years from 2010 to 2016 for applying correlation results, were used. The list of used Landsat images is given in Table 1.

Surface reflectance is the fraction of incoming solar radiation that is reflected from Earth's surface. Retrieved from satellite images by correcting for atmospheric effects, surface reflectance images approximate what would be measured by a sensor held just above the Earth's surface, without any effects from the atmosphere or illumination and viewing geometry. Surface reflectance is the most basic remotely sensed surface parameter in the solar reflective wavelengths (i.e., visible and infrared), providing the primary input for essentially all higher-level surface geophysical parameters, including vegetation indices, land cover, and land cover change etc. Because removing atmospheric effects increases the comparability between images of Earth's surface taken at different times, surface reflectance is also used to detect and monitor changes on the Earth's surface (GLCF, 2011). Many different methods exist for reducing background influence on VIs. We selected and compared two VIs that characterise the vegetation cover. Normalized Difference Vegetation Index (NDVI - Rouse et al., 1973), where:

$$NDVI = \frac{(NIR - R)}{(NIR + R)}$$

Equation 1

SAVI was specifically developed and is recommended for arid environments to reduce soil background effects on the vegetation signal and is calculated as:

$$SAVI = \frac{(NIR - RED)}{(NIR + RED + L)} * (1 + L)$$

Equation 2

The L is an adjustment factor which varies from 0-1 in accordance with soil background conditions. The recommended L factor of 0.5 was used for all images (Huete, 1988). We used field geobotanical monitoring results which show 4 degradation levels (weak, average, strong and very strong) in 45 sample points within the study area for the year 2010.

Figure 1: Research area. It is marked with a red rectangle (source: www.mapsofworld.com)

Table 1: Landsat Images used in the study

S.No	Landsat Scene Identifier	Sensor	Spacecraft Identifier	Date acquired
1	LE71550322010148PFS00	ETM_SLC_OFF	LANDSAT_7	28-05-10
2	LT51550322010252KHC00	TM	LANDSAT_5	09-09-10
3	LE71550322011247PFS00	ETM_SLC_OFF	LANDSAT_7	04-09-11
4	LE71550322012250PFS00	ETM_SLC_OFF	LANDSAT_7	06-09-12
5	LE71550322013252SG100	ETM_SLC_OFF	LANDSAT_7	09-09-13
6	LE71550322014255PFS00	ETM_SLC_OFF	LANDSAT_7	12-09-14
7	LE71550322015258NPA01	ETM_SLC_OFF	LANDSAT_7	15-09-15

They were defined by using the traditional method of routing geobotanical research methods and laboratory deciphering the Landsat satellite images. For the study of seasonal dynamics of forage on pasture reference sites laid transects 10 m^2 areas, which were carried out mowing and determined biomass of forage plants. Types of grassland pastures were allocated according to the scheme of typology (Beshko and Mukimov, 2013). Weak – vegetation is characterized by full composition and structure, good life conditions and normal resumption most species, with weak signs of deterioration of the vegetation (the appearance of traces of weed species, a slight decrease in the abundance of fodder species). Average (moderate) – noticeable adverse changes in the composition and structure of vegetation: growing an abundance of xerophytes, ephemeras and weedy species, they begin to play the role of subdominants; reduced abundance of food plants deteriorates their living condition and renewal; reduced projective cover.

Strong – the composition and structure of communities disrupted, changed set dominate and subdominants (dominated by ephemeral, uneaten, weed species). Status of fodder plants depression and renewed weakness. Pastures knocked out, the grass is sparse, low productivity. Very strong – pastures strongly stamped, indigenous communities were replaced by secondary phytocenosis with the dominance of weed species and ephemeral and very low productivity.

NDVI and SAVI methods were applied for Landsat images and the mean value for the 5*5 neighbouring pixels were calculated for each pixel of the resulting image of those methods by using software Erdas Imagine 2014. The ranges of values for 4 degradation levels were defined by correlating NDVI and SAVI values itself and mean values of them to field geobotanical monitoring results for exact points.

3. Results and Discussion

First of all, we created subset and layer stack the required bands (1-5 and 7) for all satellite images to define and show only the territory of the study area by using AOI (area of interest) method. Then NDVI and SAVI were calculated within the unsupervised classification method for the image of the 2010 year. The area was very homogeneous, so that the mean values of the pixels of the NDVI and SAVI result images were calculated as well. Appropriate values for the field monitoring sample point were derived from the images and those values correlated with degradation levels (Figure 2).

The results showed the correlation values were 0.259, 0.283, 0.261 and 0.263 for NDVI, NDVI mean, SAVI, SAVI mean methods respectively. So, we could decide that NDVI mean values were correlated with degradation levels better than other values. That's why we used those values for defining the ranges of values related to degradation levels (Table 2).

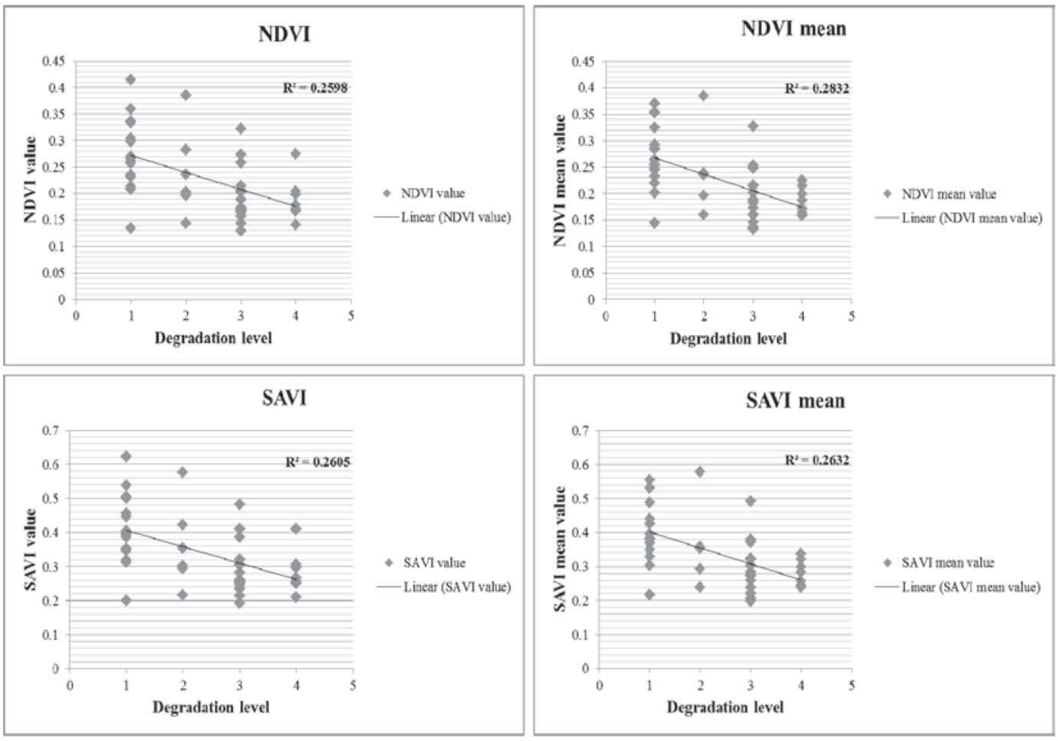

Figure 2: Comparison of NDVI, NDVI mean, SAVI and SAVI mean using degradation levels

Table 2: NDVI mean values corresponding to degradation levels

NDVI mean value	Degradation level	NDVI mean value	Degradation level
0.10-0.13	very strong	**0.20-0.25**	Weak
0.13-0.16	strong	**0.25-1.00**	no degradation
0.16-0.20	average		

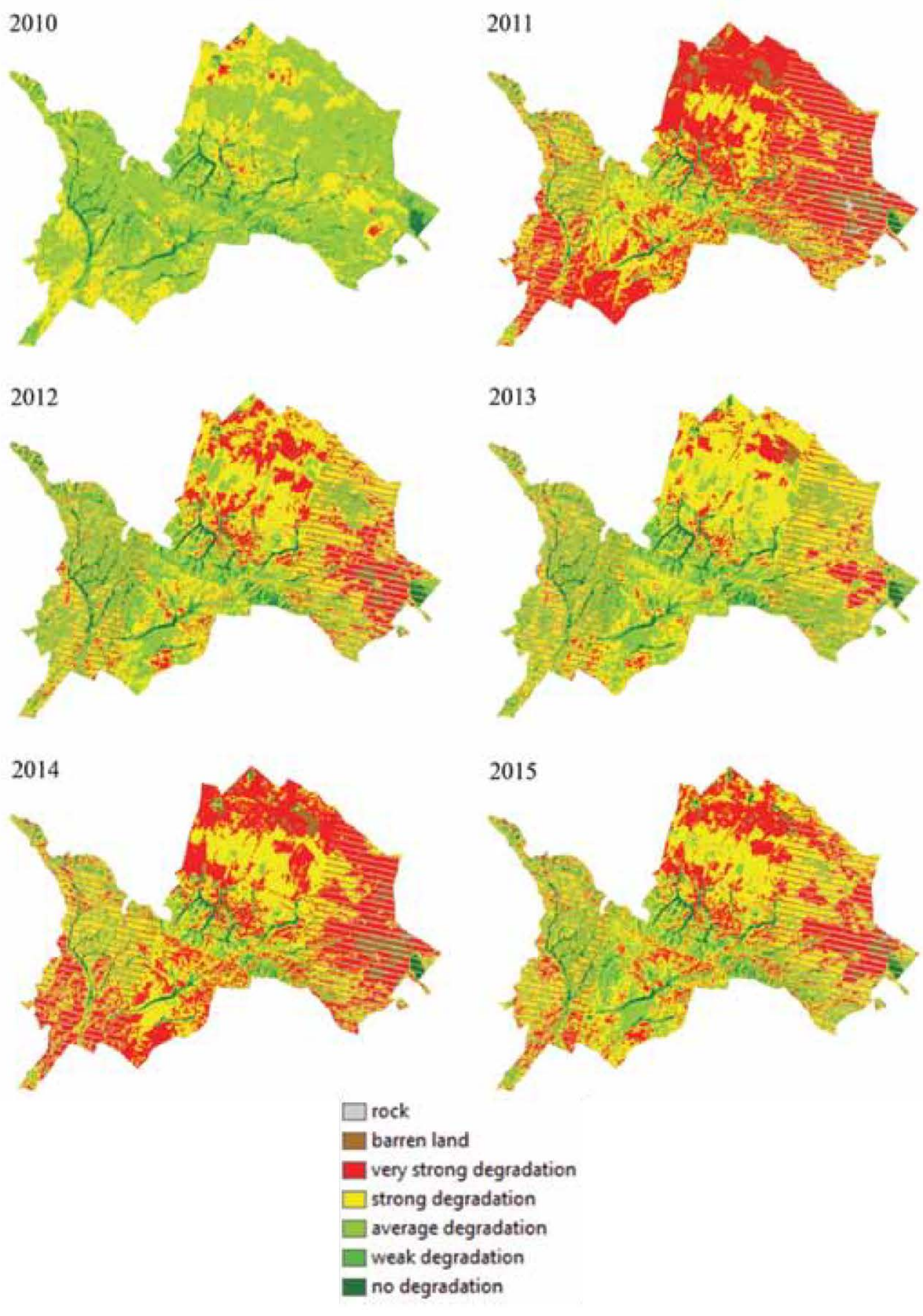

Figure 3: The dry season time series of NDVI images of the part of Forish district from 2010 to 2015

Those ranges were used for the time series analysis of the Landsat images of 2010-2015 years period in order to show the degradation level of the study area which can help us to monitor grazing impact. We obtained 6 new raster layers for NDVI from Landsat images and other 6 new raster layers for NDVI mean from NDVI images for 2010-2015 years respectively. Those NDVI mean raster layers were used to classify and show the degradation level of vegetation. In total 6 images were created for showing grazing land degradation status which can help us to monitor the grazing impact in the study area (Figure 3).

The Figure 3 shows that the years 2010 and 2013 have particularly pronounced numbers of higher NDVI values (green) than other years and the most of the territory were strongly degraded (red) in 2011 and 2014 years. Actually, a dry season time series of scenes were used because wet season scenes tend to capture the dynamics of the most ephemeral components of plant communities such as annuals. Dry season scenes are appropriate for this analysis because they are constrained to the more permanent ground cover.

4. Conclusion

This study shows that Landsat TM and ETM+ Surface Reflectance imagery can be used to delineate vegetation change in ecosystems threatened by grazing land degradation in semi-desert and desert environments such as Forish district. Vegetation indices derived from remotely sensed data are capable of estimating vegetation degradation levels on semi-desert and desert grasslands. The methodology used in this study shows quantitatively that at 30 m spatial resolution both SAVI and NDVI have comparable performance to detect vegetation cover in the study area. Nevertheless, while correlation between the vegetation indices values and degradation levels, the NDVI values were better correlated than SAVI values during our study. SAVI is still correlated to degradation level of vegetation but with a lower accuracy than NDVI.

The result map shows that the big changes of degradation levels occurred in the research area in 2010-2015 years period. The worst situation was in 2011 and 2014 with the most very strong degraded territory.

This method of analysis is very cost and time effective, as a result of the research; it can be applied to assess pasture land degradation in Forish district and also other pasture lands of Uzbekistan. In addition, dividing into zones of the area according to the degradation levels can be used for rotational pasture management and organizing measures to improve degraded lands. Hence, it is recommended to use NDVI index to produce vegetation maps of Forish district. Finally, this research confirmed the adequacy of more popular NDVI vegetation index over the SAVI in desert and semi-desert zones.

In general, we could say that grazing impact can be monitored in a rangeland ecosystem of Forish district by assessing vegetation status via remote sensing techniques using NDVI.

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