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LAND DEGRADATION ASSESSMENT IN AN AGRICULTURAL AREA OF MONGOLIA: CASE STUDY IN ORKHON SOUM

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ABSTRACT

This study presents detection of vegetation change in Orkhon soum, Mongolia, using Landsat-8 Operational Land Imager and Landsat-5 Thematic Mapper images from 2010 and 2015. Normalized Difference Vegetation Index (NDVI) image classification techniques and change detection processes were applied. The aim of this study was therefore to assess the land degradation-based reduction in the amount of green plant material in the vegetative cover and to find if there is a correlation between vegetation cover change with land use, type and soil texture. The vegetation value was divided into six classes from Highly Dense Vegetation to No Vegetation. The results show that the Less Vegetation class has increased by 11.7% and Less Moderate and Moderate vegetation classes decreased by 13.8 and 27.8%, respectively. Highly Dense Vegetation decreased by 11.3%. The settlement and forest area's vegetation NDVI value changed negatively. The loamy soils NDVI had increased by 10 pixel values. This means that some meadow vegetation cover had changed positively. NDVI Values for sandy clay loamy and loamy sand soil area had decreased more than 20 pixel values, indicating loss of vegetative cover.

Key words: Land degradation, NDVI, change detection, vegetation assessment

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1. INTRODUCTION

Mongolia has an area of 1,565 million km^2. The landscape features high and low mountains, hills and plateaus. The northern and western part of the country have high mountains, whereas the south and southeast parts are steppes and arid areas (Tsegmid 1979). Overall Mongolia is characterized by a harsh climate and sparse plant cover, which contribute to low fertility of the soil (Avaadorj 1998).

Since the 1990s when the political system changed from socialism to capitalism, the domestic animal population increased 4.5-5.6 times, especially the goat population which increased from less than 5.0 million to 20.0 million (Wang et al. 2017).

The traditional method of land use for pasture was suited to protect the soil from erosion. But in the past 50 years, a large area has been converted to cropland and cultivation as part of agricultural development (Avaadorj & Baasandorj 2007).

Mongolia has 126 million hectares of pasture, as well as 6.2 million hectares of bluffs and gullies that are not suitable for pasture, 3.0 million hectares of sand covered areas, and 20.5 million hectares of saline soil areas in arid desert. According to this estimation (Avaadorj & Badrakh 2007), only 76.5% or 96.8 million hectares of total pastureland area are currently used for pasture.

Several research projects have dealt with remote sensing and mapping in Mongolia, including mapping the forest cover and estimating its change in the forest-steppe ecological zone (Ariunzul 2008). The rangeland vegetation state of the steppe ecological zone in Mongolia was assessed, using remote sensing, by Adiyasuren (1989), and the agricultural area in Mongolia by Dorjjantsan (1975). A method for making a natural resource map using remote sensing in Mongolia was developed by Saandari (1985). Erdenetuya (2009) tried to assess and classify national land cover and pasture degradation by using high resolution satellite data.

In the desertification atlas of Mongolia, the factors of land degradation and desertification (Mandakh et al. 2015) are estimated based on desertification research. Natural factors account for 56% and human factors for 44% of the results in heavily or very heavily desert areas.

My individual research project is part of the Ecological and Land Use Issues Project (2017-2019), funded by the Ministry of Education, Culture, and Science, which is an ongoing research study in Mongolia. The Orkhon soum was chosen for this study as it is representative of multiple land uses.

Land degradation following the increase in the number of livestock and overgrazing is a serious problem. Importantly, Orkhon soum is the site of most of the land used for vegetable and fruit production in the nation. My research results can therefore be useful for local scale decision making and land use planning.

My research focused on estimating land degradation, based on satellite images, which is influenced and degraded by overgrazing and also on various land uses in an agricultural area in Mongolia.

An overall goal:

My aim was to assess the land degradation-based reduction in the amount of green plant material in the of vegetative cover, and to find if there is a correlation between any change in vegetative cover with land use type and soil texture.

The specific objectives can be listed as:
1. Learning constructive methods, which can be used to estimate land degradation
2. Producing maps of vegetation cover from two different years, using NDVI (2010, 2015)
3. Detecting the changes with NDVI between two years (2010, 2015)
4. Correlation between NDVI and soil texture and pasture type
5. Comparing and analyzing the map results

2. MATERIALS AND METHODS

2.1. Study area and land use

2.1.1 Description of study area

The research site is located the northern part of Mongolia (Fig.1), which is situated in the steppe zone (National Atlas of the Mongolian People 1990). The soum center is located at the northern part of its territory which is located between the Shariin Gol River and the Orkhon River. Here, farmers mostly plant vegetables and potatoes for household consumption (IGG 2016).

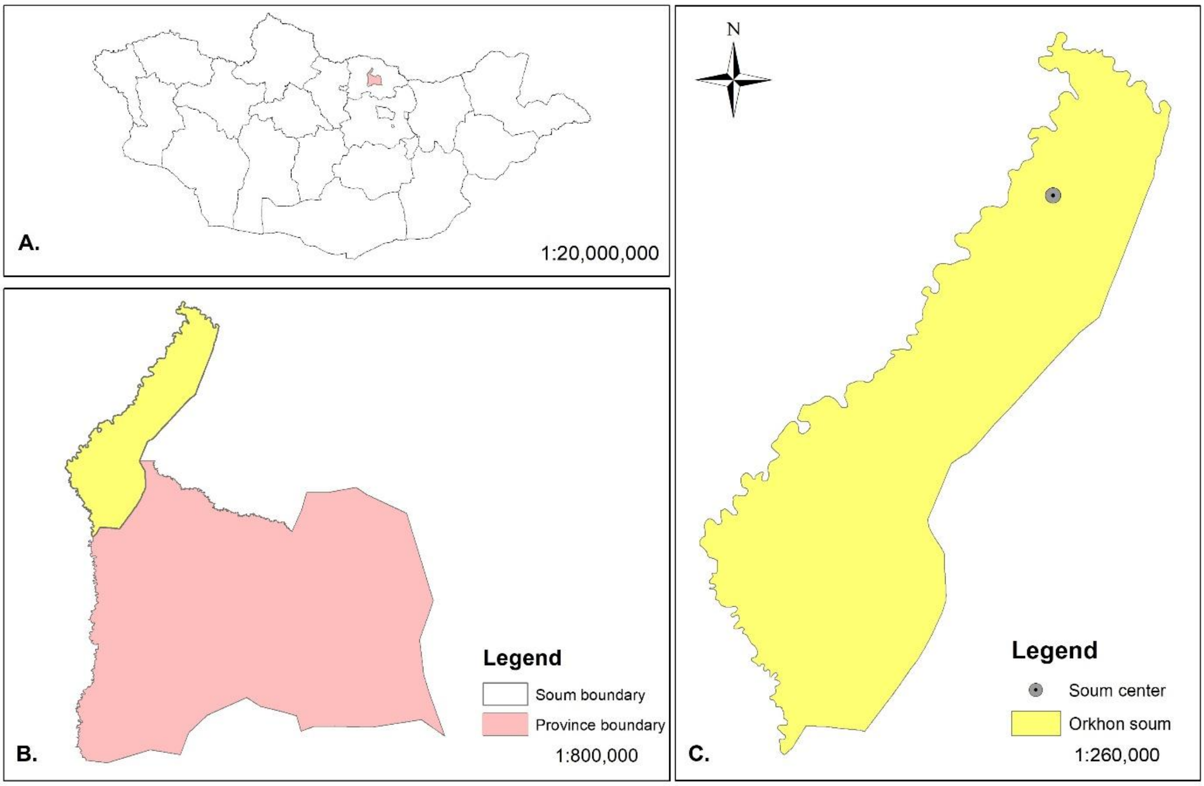
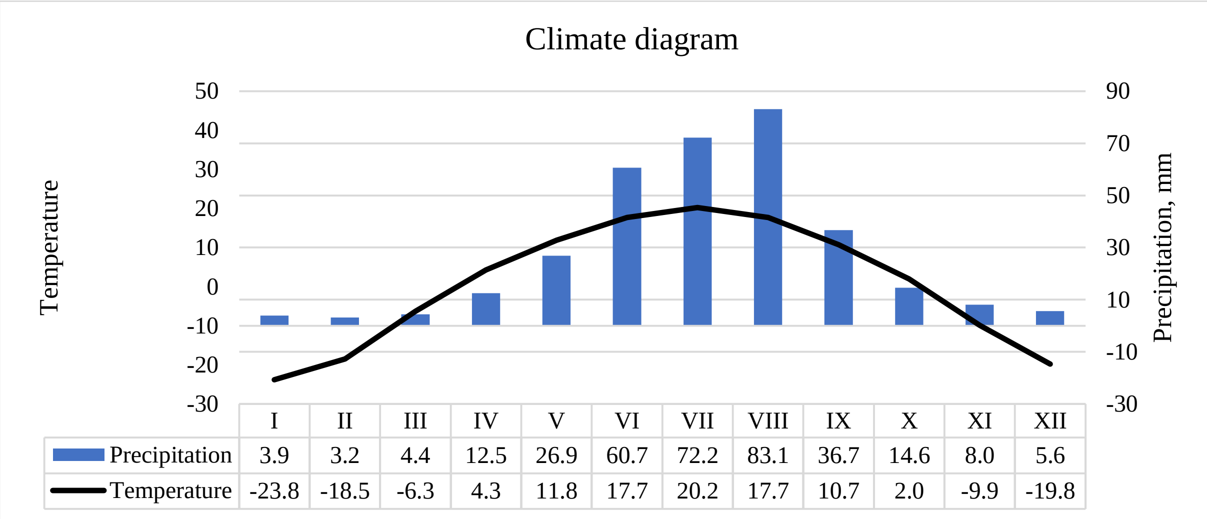


Figure 1. Map of Mongolia (A) highlighting the Darkhan-Uul province (B) where the research site in Orkhon soum (C) is located.

The elevations are between 800-1200 meters above sea level (IGG 2010). The climate conditions are very harsh and have four seasons. The average temperature in January, which is the coldest season, is -19.9˚C (Fig.2). The average temperature in July, which is the warmest season, is 22.3˚C. The average annual precipitation is 310-320 millimetres (National Meteorological Agency 2016).

Figure 2. Annual and monthly average temperature (˚C) and precipitation (mm) in the period 1984-2016. Source: Information and Research Institute of Meteorology, Hydrology and Environment.



The dominant wind is from the north and west and northwest, as in other parts of Mongolia. The frequencies from the north are 23.9%, northwest 18.3% and northeast 13.7%. In the study area, the annual mean wind speed is 1.5-1.8 m/sec. The average wind speed is 3.1-3.5 m/sec in April and May, which are the driest months.

2.1.2 Soils

In this area, most of distribution of soil types differs between the north and south sides of the mountain. Chestnut soils are most common (Table 1). Soil textures in the research area are classified as sandy loam, loamy and sandy clay loam (Fig.3). The soil thickness differs in the valleys from that in the mountains (Avaadorj 2014).

Table 1. Soil types in Orkhon soum.

Soil types	Area, ha	Percent
Kastanozem	46	0.1
Mountain chestnut soil	12664	28.6
Chestnut soil	20831	47.1
Meadow soil	9744	22.0
Alluvial meadow soil	936	2.1
Total	44221	100

The main soil texture classes according to the USDA system (Foth 1978) in Orkhon soum are presented in Table 2. About 63% is sandy clay loam (SCL) soil (Fig.3).

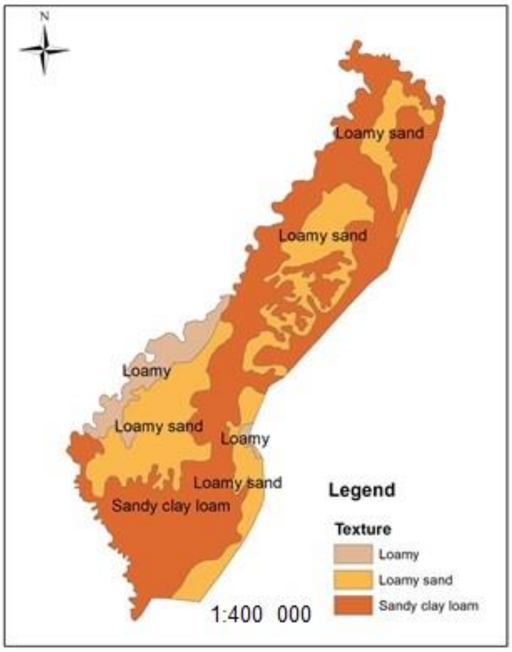


Table 2. Classification of soil texture. Soil percentage by textures.

Soil texture	Area, ha	Percent
Loamy sand	13581	30.7
Sandy clay loam	27716	62.6
Loamy	2924	6.6
Total	44221	100

The croplands and cultivated lands have chestnut soils and meadow soils. They are located mostly in the valleys and meadows between the mountains.

2.1.3 Land use

Orkhon soum has registered 39 types of different land use in 2015. Land utilization type is divided into 6 main classifications in Mongolia. Fig. 4 shows the land use map for Orkhon soum.

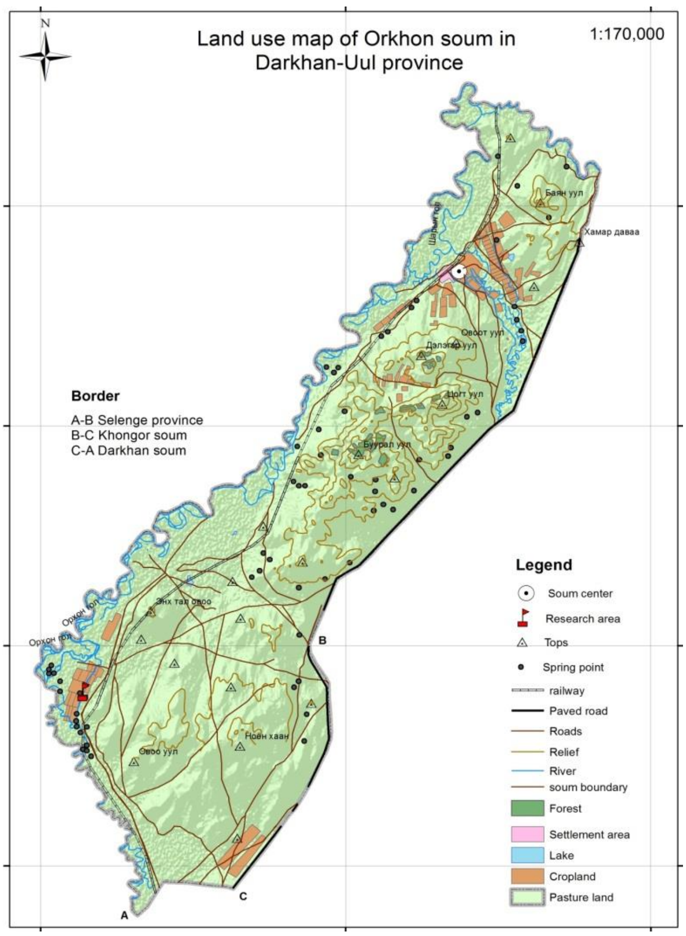


Figure 4. Land use type of Orkhon soum.

Annual land inventory is reported to the government based on this classification. In this report, the total territory covered is 44221 ha, 87.1% of the total territory being agricultural lands in Orkhon soum. The rest (Fig. 5) is used for settlement, transportation, forest and water resources, and special needs (Administration of Land Affairs, Construction, Geodesy and Cartography 2015).

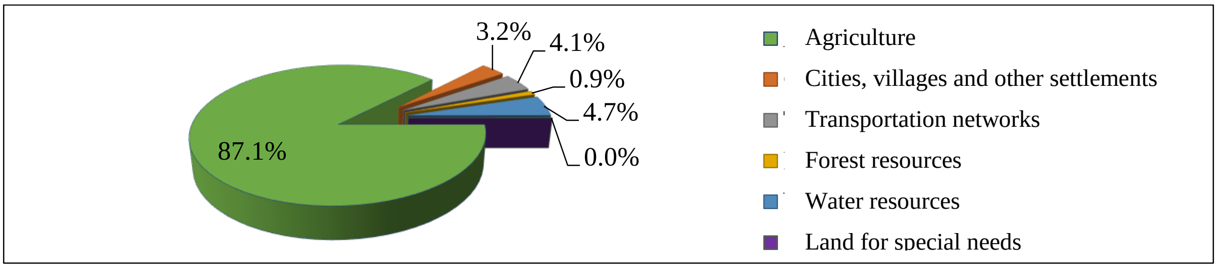


Figure 5. Land use type classification in Orkhon soum, 2015.

Approximately 89% of the total agricultural land is used for pasture, 5.5% used for hay and 5% for cultivation The rest is uncultivated land and 0.2% is used for buildings for agriculture needs (Fig.6). There are bald mountain pasture, steppe pasture and wetland/meadow pasture in Orkhon soum.

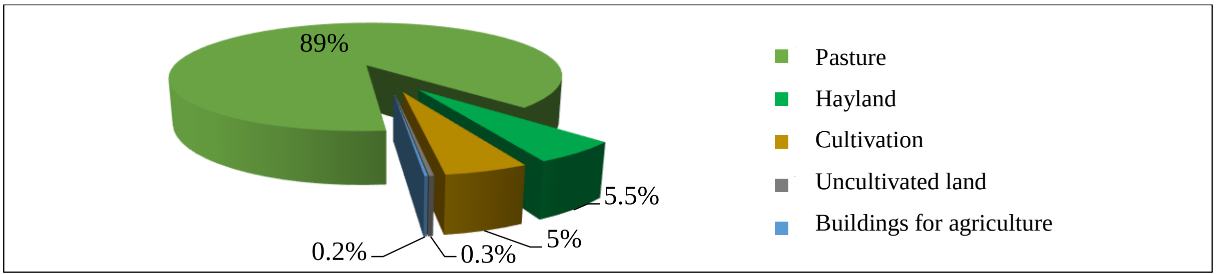


Figure 6. Classification of agricultural land in Orkhon soum, 2015.

Pasture use. Herder family movement into the area has increased since 2005. Fig. 7 shows the livestock population dynamics. Since 2010, sheep numbers have decreased but cattle numbers have increased. Pasture Carrying Capacity was assessed according to the method by Tserendash (2000). The results show that carrying capacity was exceeded by over 3 times the normal grazing pressure (IGG 2016).

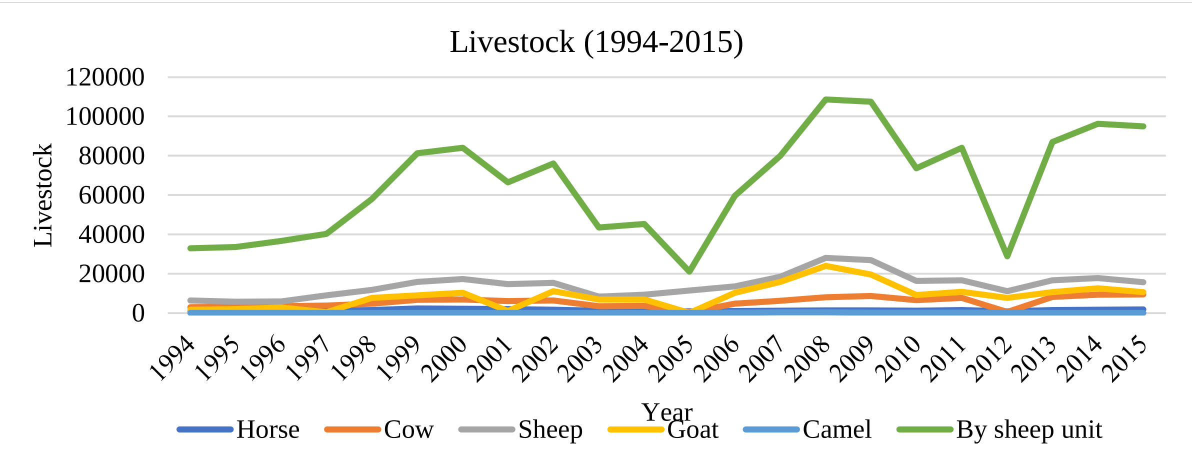


Figure 7. Number of livestock in Orkhon soum from 1994 to 2015 (Darkhan Statistics, 2015).

2.2 Methods

The assessment of land degradation and change in vegetative cover in Orkhon soum was done using the software ArcGIS (10.3) for data analysis. The analysis was carried out as follows:

a. Vegetation map based on normalized difference vegetation index. Estimating the vegetation cover on two satellite images (Table 4) by using Normalized Difference Vegetation Index (NDVI). This method was initially proposed by Rouse et al. (1974). NDVI is derived from the ratio Red (R) and Near Infrared (NIR). The Red band is Band 3 for Landsat 5, Band 4 for Landsat 8. NIR is Band 4 for Landsat 5 and Band 5 for Landsat 8.

Table 4. Description of datasets used for NDVI calculations.

Data type	Date	Path/Row	Bands and resolution	Producer
Landsat TM	23rd of August, 2010	132/025	Bands 3&4, 30 m	USGS
Landsat OLI	21nd of August, 2015	132/025	Bands 4&5, 30 m	USGS

The NDVI is the most commonly used index and has a measurement scale ranging from -1 to +1. Negative values represent non-vegetated surfaces, whereas values close to 1 have very dense vegetation (Ioan et al. 2013). The different formulas of ArcGIS can be used to calculate and display NDVI. Using the formula below, NDVI values range from 0 to 200 (rather than -1 to 1)

The NDVI formula (Keranen et al. 2014) is:

$$\mathbf{NDVI} = \frac{\mathbf{NIR-R}}{\mathbf{NIR+R}} \mathbf{*}100+100$$

Where: NIR – Near infrared
R – Red

b. Change detection. Detection of change involves the use of multitemporal data sets to distinguish areas of land cover change between dates of images (Lillesand et al. 2008). A change detection map was created by the *Image Analysis tool* in ArcGIS from NDVI values between 2010 and 2015.

c. Correlation with soil texture and land class. The *Tabulate Area tool* in ArcGIS was used to find the correlation between change detection, soil texture and land class. The tool calculated cross-tabulated areas between two datasets and outputs in a table.

A detailed description of the work flow used for NDVI analysis and change detection is shown in Fig. 8.

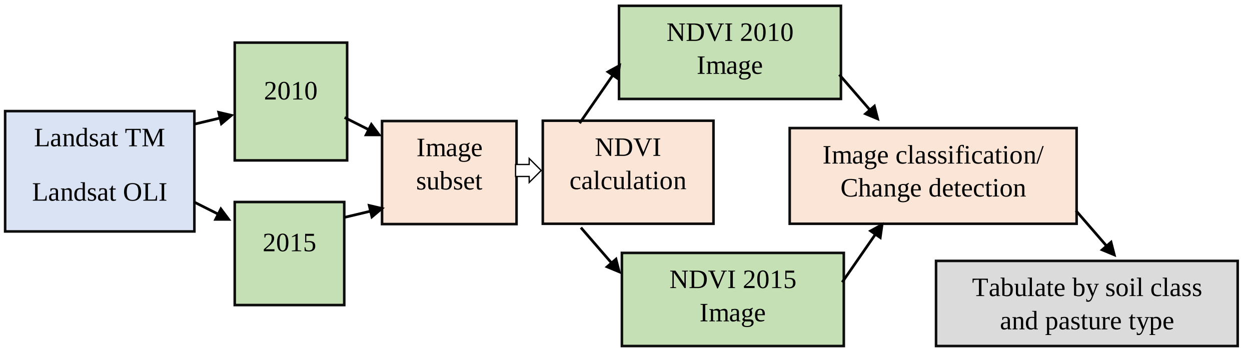


Figure 8. Flow chart of methodology.

3. RESULTS AND DISCUSSION

3.1 Vegetation cover change

These maps (Fig. 9) show the vegetation based on NDVI values from 2010 and 2015. The NDVI values are divided into six classes as described by Nath B (2014). These are: No Vegetation (105.8-109.2), Less Vegetation (109.2-122.9), Less-Moderate Vegetation (122.9-131.3), Moderate Vegetation (131.3-138.5), Dense Vegetation (138.5-145.2), Highly Dense Vegetation (145.2<).

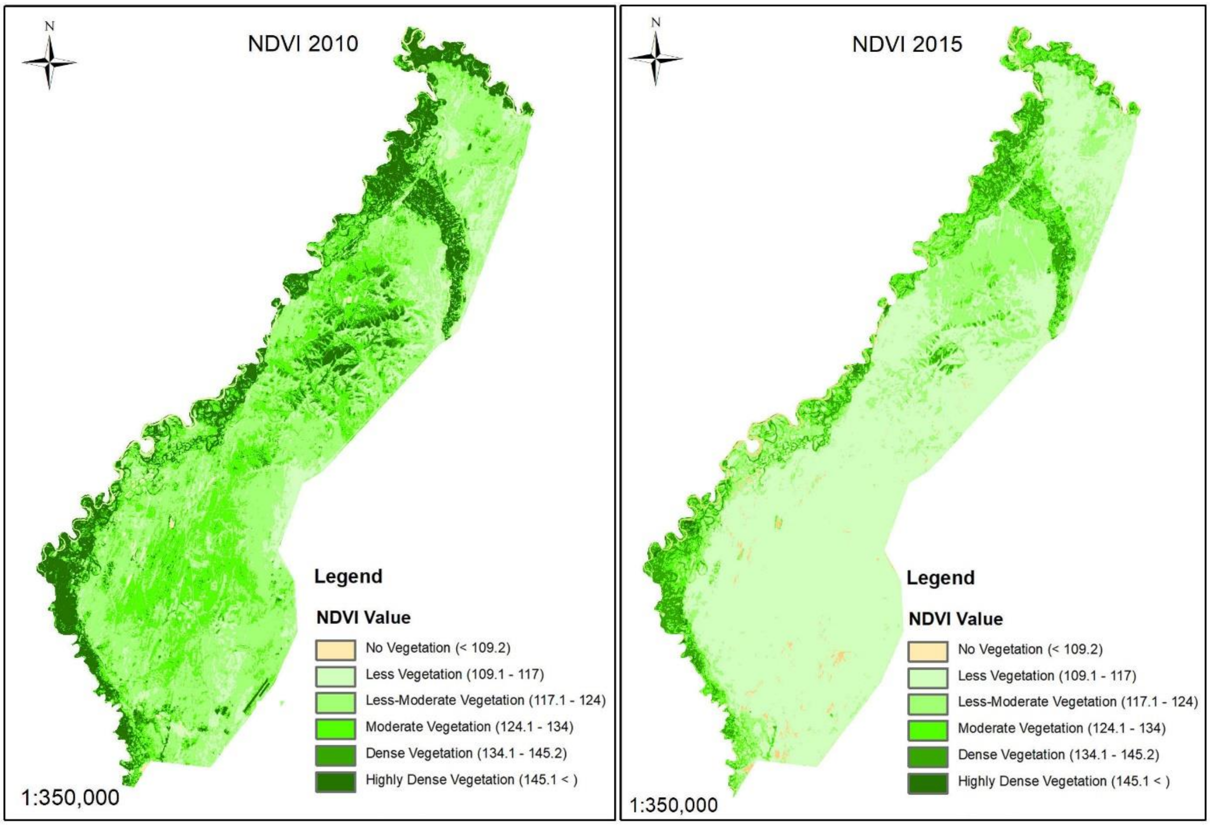


Figure 9. Vegetation maps for Orkhon soum in 2010 and 2015.

The two years of NDVI values are summarized in Table 5. The minimum value increased by 18.2 and the maximum value decreased by 17.6.

Table 5. The NDVI values and the changes between 2010 and 2015.

NDVI value	**2010 NDVI**	**2015 NDVI**	**Changes**
Minimum	58.8	77.0	18.2
Maximum	172.6	155.0	-17.6
Mean	132.2	117.9	-14.3
Standard deviation	10.8	8.0	

In Fig.10 we can see how the NDVI pixel values changed between two years. In 2010, most pixel values were between 121-133, whereas in 2015 most pixel values were between 109-121.

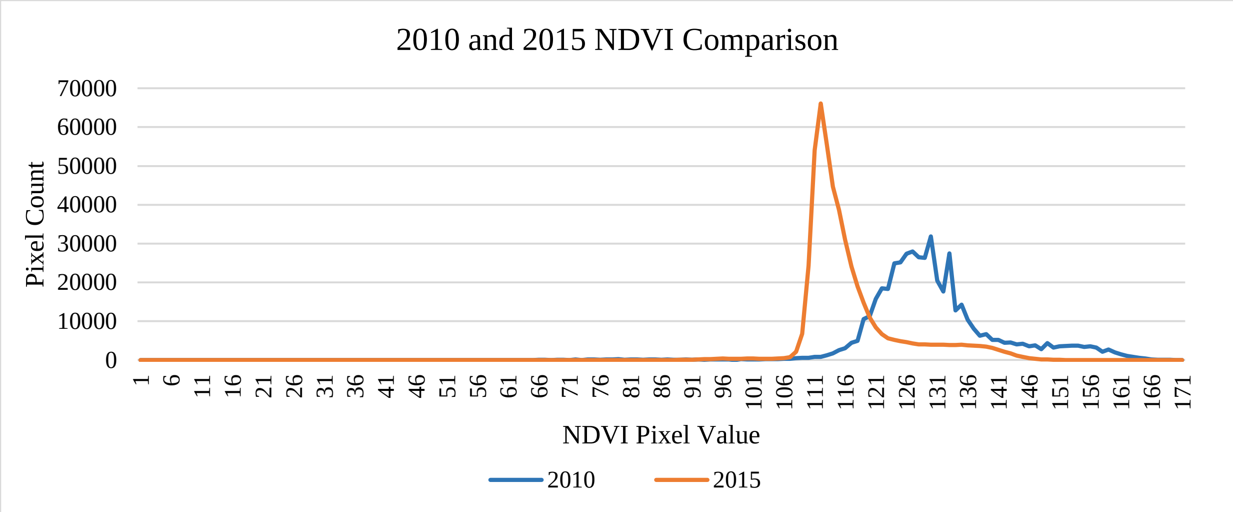


Figure 10. Graph for NDVI pixel values in 2010 and 2015.

In Fig. 11 we can see that the Less Vegetation pixel values were 11.7% in 2010, but 2015 the percentage became 64.8%. The Less Moderate and Moderate Vegetation decreased by 13.8-27.8%. This that means most of the area converted from less moderate and moderate to Less Vegetation. Even Highly Dense Vegetation decreased by 11.3%.

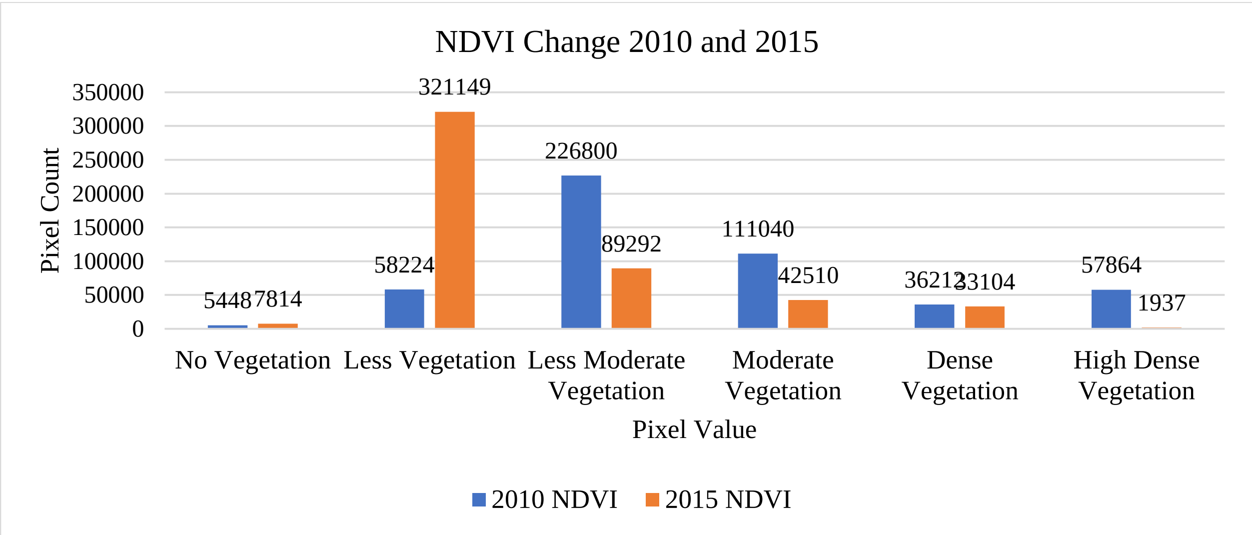


Figure 11. Graph for NDVI Pixel values in 2010 and 2015.

3.2. Vegetation cover change and soil texture.

The different NDVI values in 2010 and 2015 were compared to soil texture (Fig. 12). It can be concluded that the areas converted from Dense Vegetation and Moderate Vegetation to Less Vegetation were primarily in loamy sand areas.

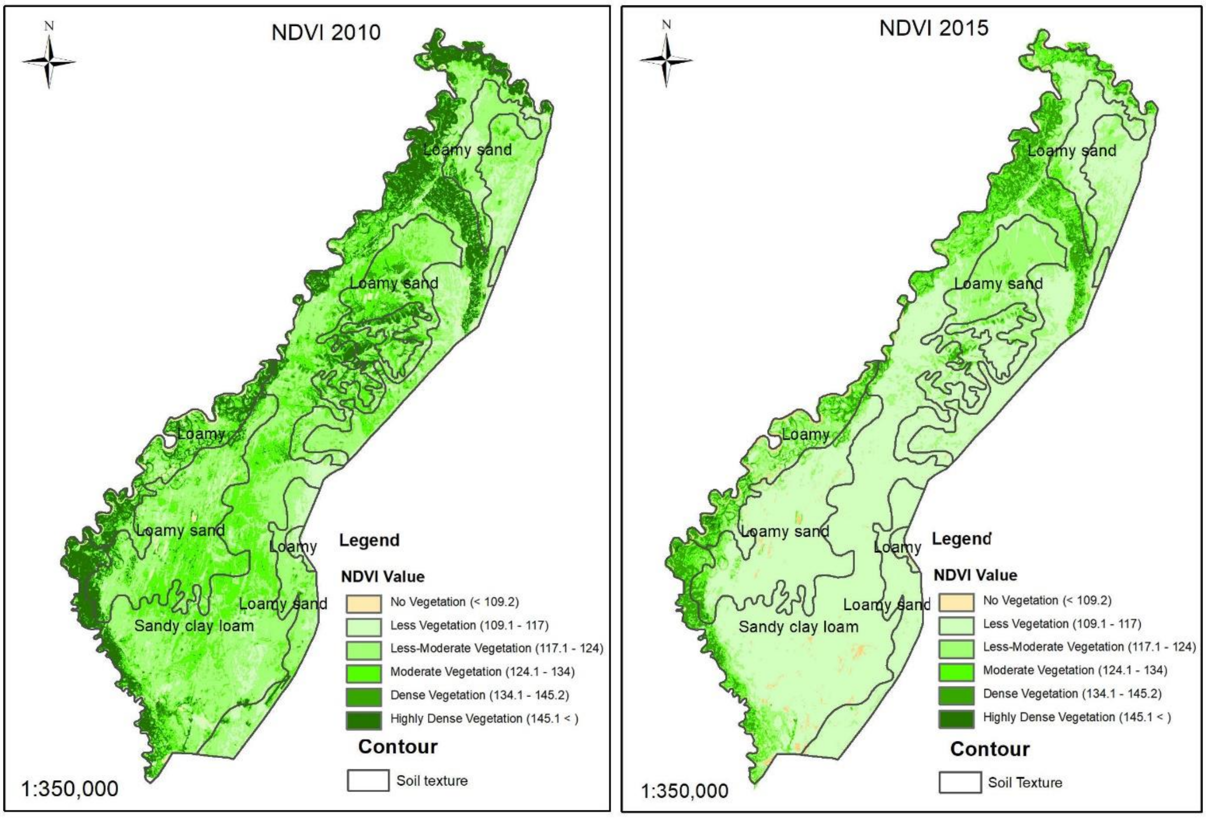


Figure 12. Vegetation map based NDVI value and soil texture.

Here we can see (Table 6) that the NDVI mean value for loamy sand had decreased by 13.9, by 11.7 in loamy soil, and by 14.1 in sandy clay loam soil.

Table 6. NDVI pixel values categorized by soil texture.

Soil texture	NDVI value	2010	2015	Change
Loamy sand	Minimum	72.0	77.0	+5
	Maximum	172.0	152.0	-20
	Mean	129.8	115.9	-13.9
	Standard deviation	*7.8*	*5.0*	
Loamy soil	Minimum	63.0	86.0	+23
	Maximum	171.0	153.0	-18
	Mean	134.7	123.0	-11.7
	Standard deviation	*16.3*	*10.8*	
Sandy clay loam	Minimum	61.0	86.0	+25
	Maximum	172.0	155.0	-17
	Mean	132.4	118.3	-14.1
	Standard deviation	*11.0*	*8.5*	

3.3 Vegetation cover change and land class

The differences between the NDVI values for 2010 and 2015 were tabulated by land use type and pasture types, as presented in Fig. 13. The results showed that the vegetation cover value was converted from Dense Vegetation and Moderate Vegetation to Less Vegetation in meadow and steppe pastures.

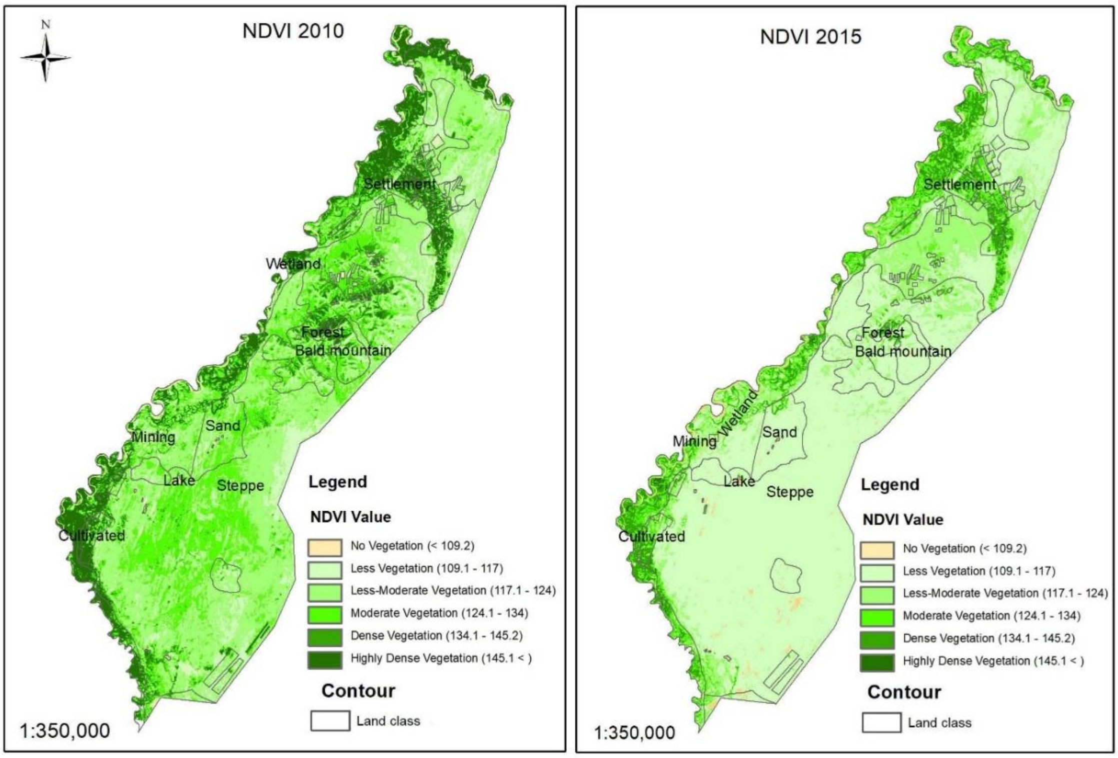


Figure 13. Vegetation map based NDVI value and land, pasture type.

Table 7. NDVI pixel values categorized by land and pasture type.

Land and pasture type	NDVI value	2010	2015	Change
Forest	Minimum	116.0	111.0	-5
	Maximum	169.0	145.0	-24
	Mean	145.0	124.7	-20.3
	Standard deviation	*14.4*	*8.7*	
Bald mountain pasture	Minimum	75.0	98.0	23
	Maximum	172.0	155.0	-17
	Mean	129.6	116.3	-13.3
	Standard deviation	*8.7*	*4.2*	
Steppe pasture	Minimum	72.0	78.0	6
	Maximum	170.0	153.0	-17
	Mean	129.4	114.9	-14.5
	Standard deviation	*6.8*	*4.3*	
Meadow/ wetland pasture	Minimum	58.0	84.0	26
	Maximum	172.0	155.0	-17
	Mean	137.9	125.4	-12.5
	Standard deviation	*15.6*	*10.7*	
Cultivated land	Minimum	66.0	89.0	23
	Maximum	169.0	154.0	-15
	Mean	134.1	121.5	-12.6
	Standard deviation	*12.6*	*8.8*	
Settlement area	Minimum	101.0	106.0	5
	Maximum	170.0	152.0	-18
	Mean	140.5	127.6	-12.9
	Standard deviation	*12.8*	*8.5*	
Lake and water body	Minimum	72.0	77.0	5
	Maximum	160.0	136.0	-24
	Mean	111.9	109.0	-2.9
	Standard deviation	*20.1*	*11.2*	

We can see in Table 7 that the NDVI mean value for forest area decreased by 20.3, for meadow and steppe pasture decreased by 17.0, and for bald mountain pasture decreased by 13.3.

3.4 Vegetation cover change detection

Change detection of the differences in NDVI values from 2010 to 2015 was ascertained and is shown in Fig. 14 and Fig. 15. To investigate the correlation between change detection by soil texture the results are shown in Fig. 14.

The NDVI for the loamy soils increased by 10 pixel values. This means that in some of the meadow areas the vegetation cover had increased. Sandy clay loamy and loamy sand soil areas decreased more than 20 pixel values, indicating a loss of vegetative cover.

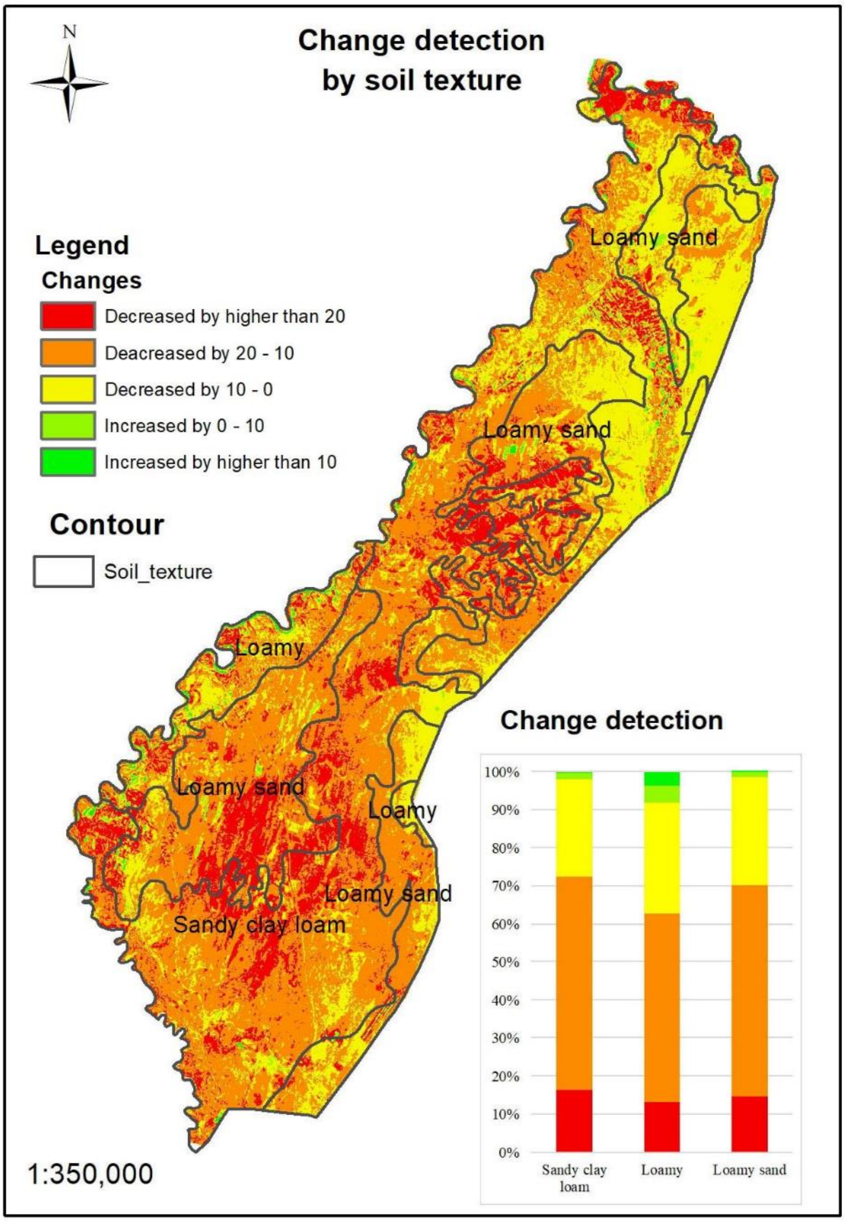


Figure 14. Change detection between 2015 to 2010 and a graph showing the change in correlation with soil texture.

The map in Fig 15 shows change detection between the two years by land use and pasture type. This shows that forest and settlement area NDVI values were decreased by more than 20 pixel values, indicating loss of vegetative cover. Lake and meadow area NDVI increased, and the pixel value for cultivated land increased probably because of different types of planted vegetables.

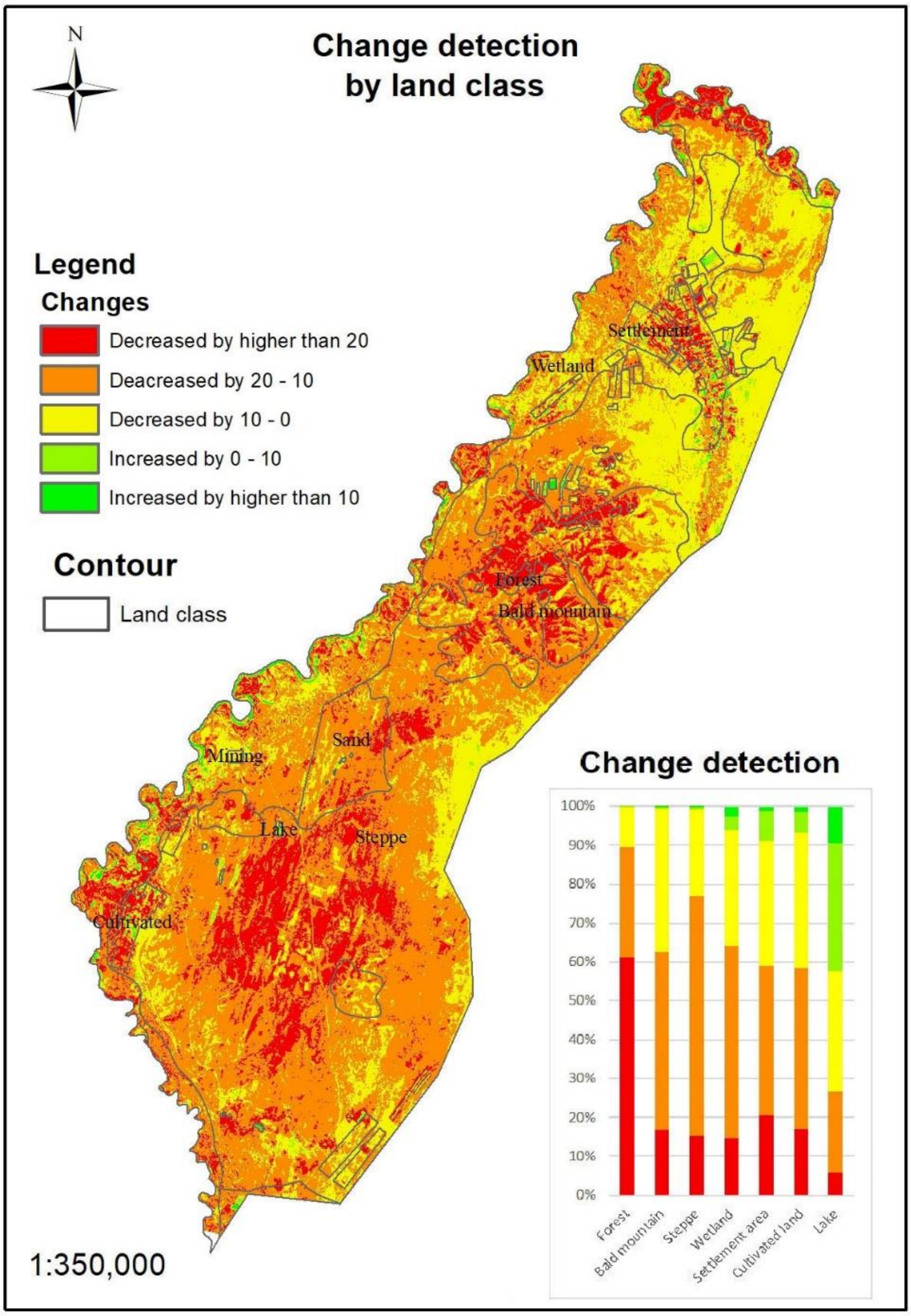


Figure 15. Change detection between 2015 to 2010 and a graph showing the change in correlation to land class, pasture type.

4. CONCLUSION AND RECOMMENDATIONS

Through this study, the results show that the multi-temporal Landsat time series has immense potential for analysing vegetation changes in Orkhon soum, in the northern part of the Mongolian steppe zone.

To assess and quantify vegetation cover changes, the post classification change detection has proved to be very efficient in identifying vegetation changes during the period of 2010-2015. It has shown that the greatest change was in the Less Vegetation class, which had increased by 23460 hectares (11.7%). The Less Moderate and Moderate vegetation classes decreased about 6114.9 – 12269.8 hectares, respectively (13.8-27.8%). This means that the largest areas had converted from Less Moderate and Moderate to Less Vegetation. Highly Dense Vegetation decreased by 4990 hectares (11.3%).

In conclusion, it can be said that the spatial analysis presented can be used in the assessment of areas with vegetation cover changes depending on various factors. The accuracy of the assessment can be higher if we use images from the same satellites.

Restoration activities or combating sand distribution, where land has become covered by sand, are necessary. And it is important to control overgrazing through decreasing livestock numbers or using intensive livestock grazing management.

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