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VEHICLE OFF-ROAD EROSION ASSESSMENT IN SOUTHERN MONGOLIA

Davaadorj Davaasuren
School of Arts & Science, National University of Mongolia,
University street-1, P.O-46a. Box 33
Ulaanbaatar 14201, Mongolia
davaadorj@num.edu.mn

Supervisors:
Jóhann Þórsson
Soil Conservation Service Iceland
johann.thorsson@land.is

Kristín Svavarsdóttir
Soil Conservation Service of Iceland
kristin.svavarsdottir@land.is

ABSTRACT

Off-road-related degradation is one of the worst problems of land degradation in Mongolia. Currently, Mongolia has over 50,000 km of roads and tracks used for transport and the latter are especially common around mining activities. The aim of this study was to evaluate two selected potential and feasible methods to assess off-road track-related degradation, both within the tracks themselves and in the immediate surroundings.

The two different approaches used in this study were NDVI (Normalized Difference Vegetation Index) used to assess the impact on larger scales, and local track experiment at transects running perpendicular to the tracks for estimating local impacts to be able to further establish the track impact on the immediate surroundings.

The results indicate that lower NDVI values, corresponding to less vegetation cover, are consistently found in closer proximities to the tracks. The track experiment showed that after the track had been driven 50 times, the surface had subsided up to 2.8 cm. Soil bulk densities increased by 1.66 gr/cm^3 and 2.12 gr/cm^3 at 5 and 20 cm, respectively. Soil moisture and porosity decreased by 30% in subsoil on average. The soil erosion estimation was 300 t/ha^2 on off-road tracks.

Key words: Off-road driving, NDVI, land degradation, soil erosion

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1. INTRODUCTION

The world's road systems are constantly expanding, both as paved highly engineered roads, but also as gravelly roads or even primitive tracks (Alisa 2007; Webb and Whilshire 1983). Pollution and degradation are potential environmental problems related to poor road systems and has been a recent focus of several authors (Adams et al. 1982; Soane et al. 1981; Webb et al. 1983; Bednap 2002; Seutloaki et al. 2010; Safari et al. 2013). Land degradation related to primitive roads, and especially off-road tracks, is a process involving loss of vegetation, soil erosion and subsoil compaction (Clevenger et al. 2003; Forman, 2003; Poteete, 2012). A better understanding of this is needed, followed by development of more advanced approaches to measure the environmental impact and monitor land degradation.

Vehicle numbers have increased with economic development during recent decades in Mongolia (Shen et al. 2006; Batkhishig 2016; Byambabayar 2017). The road system in Mongolia includes about 50,000 km of roads, of which 12,000 km are paved roads, 5,000 km are gravel roads, and the remaining are primitive tracks (Batjargal et al. 2006; Onon 2010). Road or track conditions are oftentimes poor, so parallel tracks start developing parallel to the original route. However, little information exists about the extent of these tracks and their impact. The only estimate available on the area affected by off-road travel suggests that over 120,000 ha in Mongolia are affected by off-road track driving (Keshkarat 2012). That is a larger area than all the cultivated land in Mongolia (Batkshishig 2016).

Several studies have assessed the effects of vehicle numbers on environmental conditions like soil erosion, soil compaction and dust emissions (Shen et al. 2006 Byambaa and Muryama 2012). For example, Shen et al. (2006) studied re-vegetation rates in abandoned roads in rangelands. They found that after 10 to 15 years most of the areas had reclaimed vegetation cover but the species composition had changed as invasive weed species were now dominating. Byambaa and Takashi (2008) estimated soil erosion rates and changes in soil properties around off-road tracks in northern Mongolia. Their results indicated that off-road driving caused degradation of the habitat. Given the negative environmental consequences of off-road driving, there is an increasing need to develop advanced approaches to detect and monitor the expansion and environmental impact of off-road tracks.

Since the 1970s, many approaches based on remote sensing analyses have been developed to detect land cover change and as an aid in soil quality mapping (Mckeown et al. 1985; Gruen and Li 1995; Yongecheol et al. 2003; Chaudhuri et al. 2012; Quan et al. 2014). They use features, such as reflectance at various wavelengths, incl. colour, texture and shapes, to identify surface elements and properties using remote sensing imagery (Trinder and Wang 1998; Suetens et al. 1992), Identifying roads or tracks is a common procedure (Hazarike and Honda 2001; Hormese 2016; Mnih and Hinton 2013; Ojo et al. 2016; Safari et al. 2013). The potential disturbance associated with off-road tracks should also be detectable using remote sensing analyses as it is expected to impact surface properties such as vegetation cover and topsoil properties, which all are possible to identify using remote sensing techniques.

However, these techniques have their limits as they cannot provide direct information on changes, such as subsoil compaction or the amount of topsoil being lost. Understanding how these changes are linked with other track-induced degradation is critical to assess the environmental consequences of off-road driving (Webb et al. 1983; Dewidar et al. 2016). Thus, field measurements in addition to remote sensing data are needed to fully understand the impacts of off-road driving.

The main objective of this study is to evaluate suitable approaches to monitor off-road areas and determine their influence on soil quality. Specifically, to use remote sensing methodologies to identify land degradation related to off-road driving areas. In addition, a field experiment was conducted to assess changes occurring at finer scales, such as subsoil compaction and soil erosion rates.

2. METHODS

2.1 Study area

The study was conducted in Gurvantes soum in Omnogovi aimag, southern Mongolia (Fig. 1). This area was selected because of high human activity, including coal mining, overgrazing and tourism. There are three active coal mining sites in the area, with correspondingly heavy truck traffic and sprawling track development.

For the remote sensing analyses, two different areas were selected: a coal mining site with corresponding heavy truck traffic (see “Coal mining” in Fig. 1) and an area close to the town of Gurvantes with off-road tracks associated (see “Gurvantes town” in Fig. 1).

For the field experiment to assess the finer scale soil changes related to the off-road track traffic, an area east of the mining site was selected (see “Experiment” in Fig. 1).

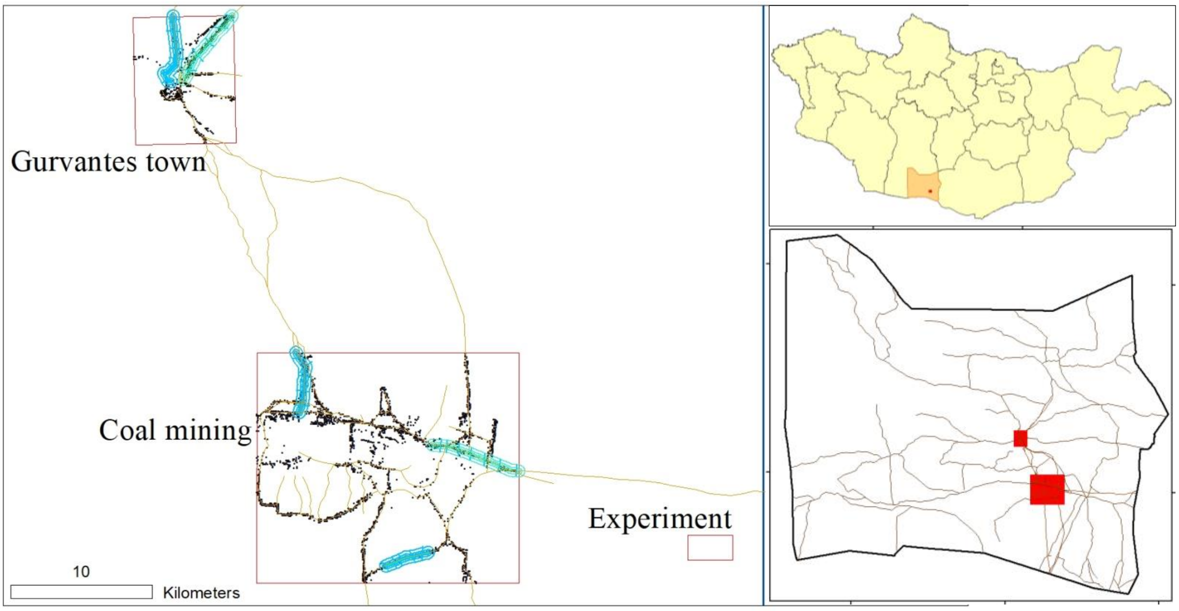

Figure 1. The location of the three study areas in Gurvantes soum in Omnogovi aimag, southern Mongolia: Gurvantes town, the coal mining site and the experimental site where the off-road track traffic impact study was conducted. The blue and green buffers shown at Gurvantes town and the coal mine indicate where NDVI transects were calculated - see text for clarification.

The dominant habitat types in the study area are desert steppe and arid land (Gobi Desert). The topography is dominated by small mountains, surrounded by wide valleys. The area lies within the dry climatic zone of Mongolia (Tsegmid 1964). It has dry and warm summers (30° C in July) and cold and frosty winters (-11° C in January). Most of the area receives less than 100 mm of precipitation per year (Davaadorj et al. 2016). Annually, more than 40 days have high winds, and dust storms are frequent in the area.

The vegetation of the study area consists of sparse, drought-tolerant perennial shrubs (*Reaumuria songorica*, *Salsola passerina*, *Anabasis brevifolia*) with less than 20% cover (Dorjgotov 2003; Dash 2010; Orkhonselenge 2016; Batkhishig 2016). The main soil types in the area are *Aridic Leptosols* in the flat areas and *Gypsisols yermic* in the mountains and hills (National Atlas of Mongolia 2009).

2.2 Methodology

Two different approaches were used in this research to identify off-road track impacts: Normalized Difference Vegetation Index (NDVI) and a field experiment simulating off-road track driving (see Fig. 1). NDVI analysis provides information about the spatial and temporal distribution of vegetation communities, vegetation biomass, land degradation in different ecosystems in around the world, and there are numerous possible applications developed for ecological and environmental purposes (Natalie et al. 2005; Jiang et al. 2006; Bao et al. 2015; Al-doski et al. 2013; Bajgain et al. 2015; Bahrawi et al. 2016). NDVI is an index based on the proportion of red and infra-red light being reflected from the surface of the Earth. This index is especially sensitive to the green colours reflected by green plants (Bhandari and Kumar 2012). It can therefore be used to estimate vegetation cover and density. NDVI values for given pixels ranges from -1 to +1, where -1.0 and +1.0) indicate no vegetation cover and total vegetation cover (or high density of chlorophyll), respectively (Tucker 1979; Meera et al. 2015; Hu et al. 2008; Zhang et al. 2009). NDVI data are easy to obtain from remote sensing imagery. In this study, the free Landsat8 data were used (www.usda.gov). The bands used were Band 5 (RED) and Band 4 (near-infrared/NIR). The resolution was 30m and the imagery was acquired on August 16th, 2017 at 12:00am. ArcGIS v.10.3.1 (2016) was used for data processing.

2.2.1 Remote sensing based analysis

A buffer of 200 m was calculated around tracks close to Gurvantes town and the coal mining site as shown in Fig. 1. A total of 28 transects were established within the buffers, running perpendicular to the tracks with their centre at the track centre. NDVI values were then used to compare changes at 30 m intervals, using the pixel dimension (see Fig. 2).

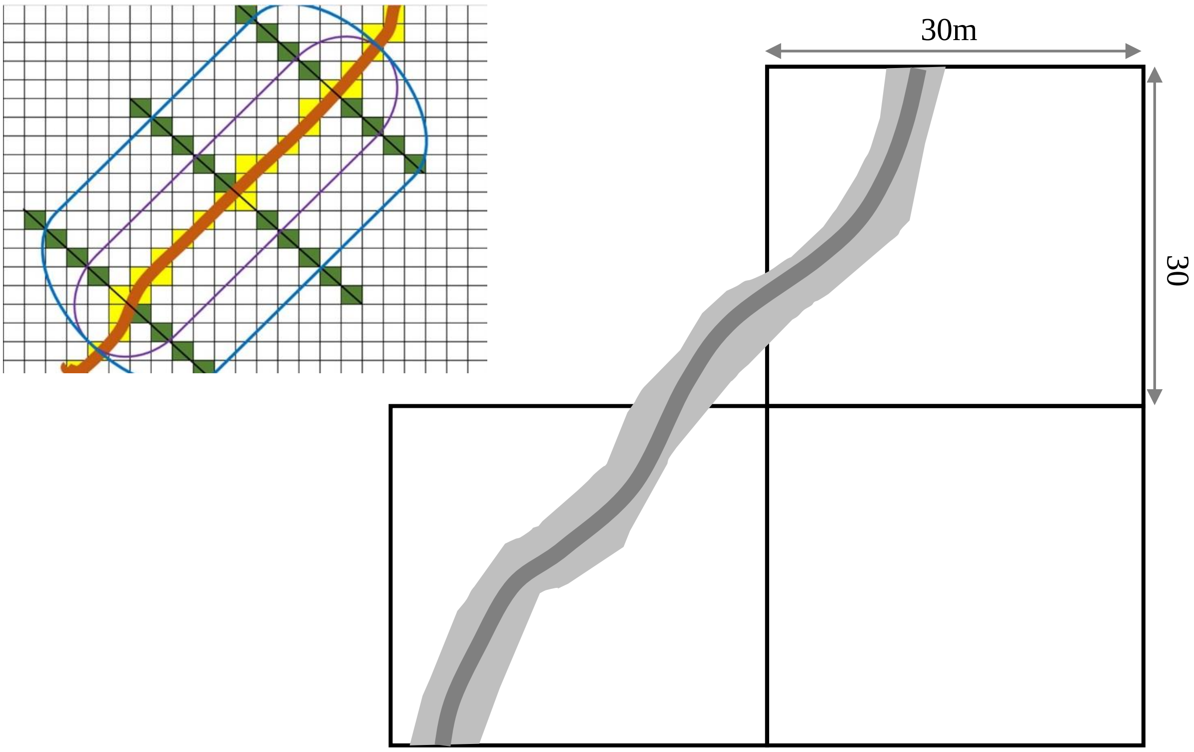

Figure 2. A schematic drawing showing how NDVI was used to analyse the potential impact tracks have on their immediate surroundings. After the tracks had been identified on the Landsat8 imagery, a buffer of 500 meters (0 m, 90 m and 210 m in both directions) was calculated using ArcGIS v.10.3.1 (2016). The Landsat8 NDVI data have 30m pixel size. A perpendicular transect was then established across the track stretching 210 m in both directions, hence covering 7 pixels or NDVI values, as shown in the insert, top left.

Remote sensing data must be manipulated in a proper way prior to obtaining NDVI values, as is shown in Fig.3. The image processing steps that were followed to obtain the NDVI values and extracting tracks using ArcGIS v.10.1 are shown in Figure 3.

2.2.2 Feld experiment and to assess the soil quality changes

The off-road track experiment was located at a plate steppe near the coal mining roads (Fig.1) and conducted in June 2016. To simulate driving, a 1.8 tn vehicle was driven 100 m, which were then subsequently used to measure soil quality changes and to compared them to conditions before the experiment (Li et al. 2004; Li and Lindstrom 2001). One trail was created (Fig. 4). Surface changes, soil bulk density and water infiltration was measured after each 10 runs to get an estimate of surface erosion and soil compaction (Fig.5).

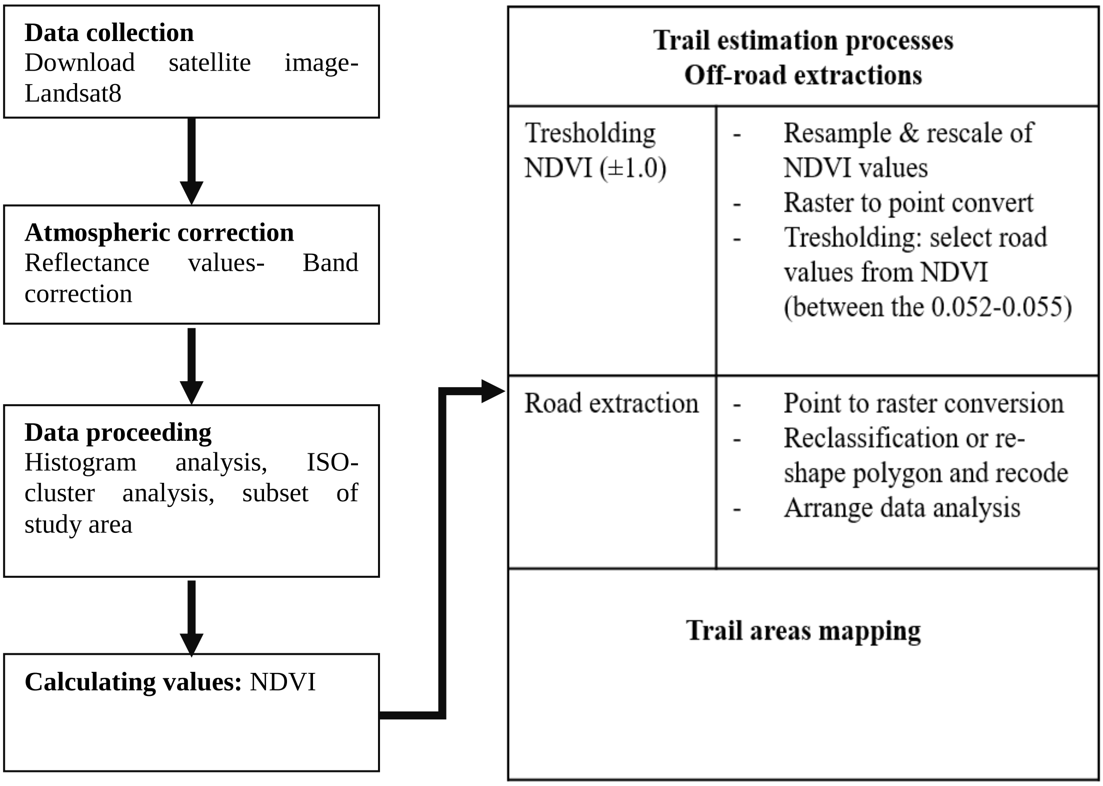

Figure 3. Flowchart of data compilation to obtain NDVI data and identifying off-road tracks.

Figure 4. The off-road track simulation experiment. A 100-m stretch was driven 50 times to simulate the effect of typical off-road driving in southern Mongolia.

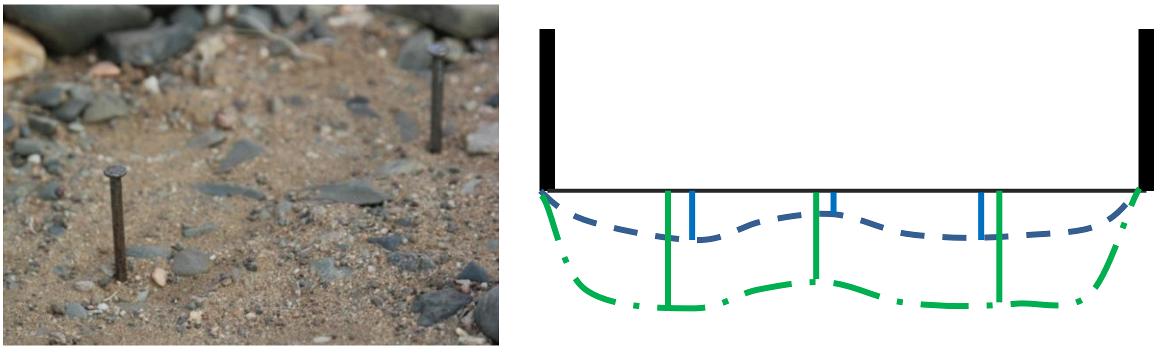

Figure 5. Soil surface change measurement. Pins were used for measuring soil loss.

Sampling was done at the track and 15 meters out from both sides. Soil samples were taken at 0-5 cm, 5-10 cm, 10-25 cm, and 25-40 cm. All soil samples were collected using 5 cm and 15 cm long hand-augers. Soil samples were air dried for 24 hours and passed through a 2.0 mm sieve prior to laboratory analysis. Soil bulk density, moisture and porosity data were obtained using the core method (Blake and Hartge 1986). Organic matter was measured by the Wet Combustion method (Nelson and Sommers 1982) and Available P and K were determined using the Olsen method (Olsen and Sommers 1982).

An approach based on Nasri et al. (2013) was used to estimate soil loss from the track, as listed below:

1. To calculate the average cross-sectional area of the rill,
   CROSS –SECTIONAL AREA (m^2) = WIDTH (m) x DEPTH (m)
2. To calculate the volume of the soil lost from the rill,
   VOLUME LOST (m^3) = CROSS –SECTIONAL AREA (m^2) x LENGTH (m)
3. To convert the total volume lost to a volume per square meter of catchment (or contributing area).
   SOIL LOSS (m^3/m^2) =VOLUME LOST (m^3) ÷ CATCHMENT AREA (m^2)
4. To convert volume per square meter to tone per hectare.
   SOIL LOSS (t/ha) =SOIL LOSS (m^3/m^2) x CONVERSION to (t/ha)

3. RESULTS

3.1 NDVI indexes

Fig. 6 shows the NDVI map for the selected study areas. High NDVI values, indicating presence of vegetation cover (chlorophyll), are presented as green, whereas low values, indicating bare surfaces, are shown in red. Intermediate areas are shown in yellow. The NDVI values were classified into seven groups based on the index distribution: group 1 (1.000 - 0.280), group 2 (0.280 - 0.020), group 3 (0.020 - -0.035), group 4 (-0.035 - -0.059), group 5 (-0.059 - -0.090), group 6 (-0.059 - -0.090), group 6 (-0.090 - -0.130), and group 7 (-0.130 - -1.000), with groups 1 and 7 being land in the best condition and the worst condition, respectively.

The NDVI pattern in Fig. 6 reflects observed vegetation cover in the respective areas. Many negative pixels were detected based on the NDVI classifications. For those pixels, degraded area detection using negative NDVI thresholding is shown in Fig.7.

NDVI frequency of degraded and good vegetated area, standard normal function of NDVI values, indicated that most of the positive values occurred in the vegetated area of grassland and several negative values were found in off-road track values from thresholding analysis (Fig.7).

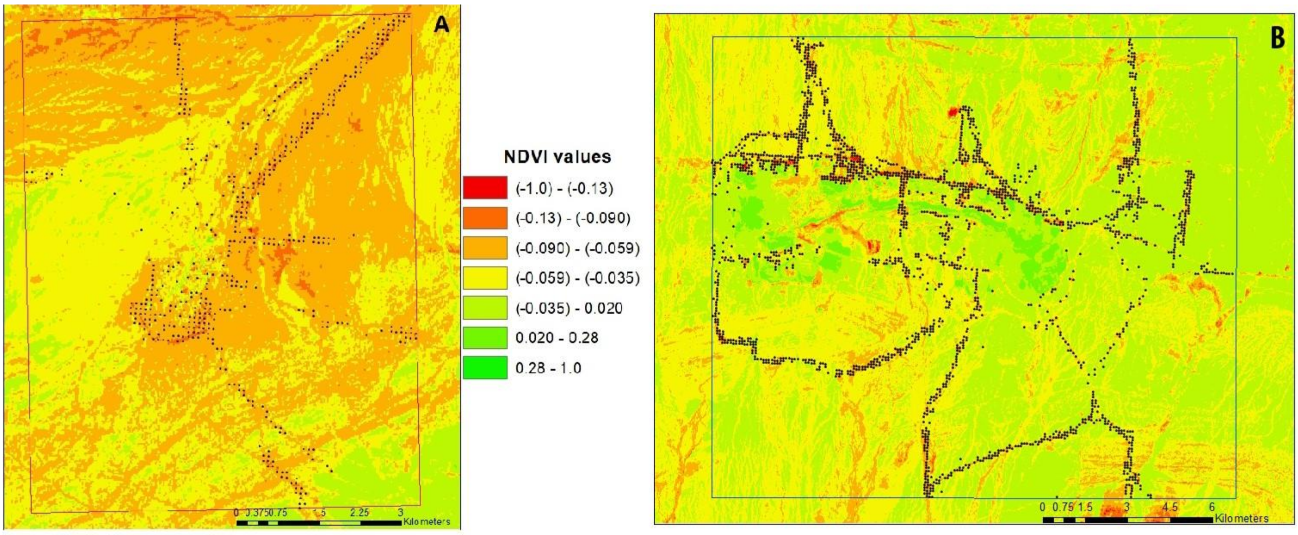

Figure 6. NDVI values of the study areas. A) Gurvantes town and B) the coal mining area. Black dots are pixels with NDVI value of -0.094, which represent off-road tracks.

3.2 Histogram analysis

Histograms were created for both the off-road track detection from NDVI trend and grassland areas in the study area, see Fig. 7. The frequency of NDVI values provide the positive 0.03 values that dominated the grassland, and negative -0.02 values were found in the NDVI from off-road track detected areas.

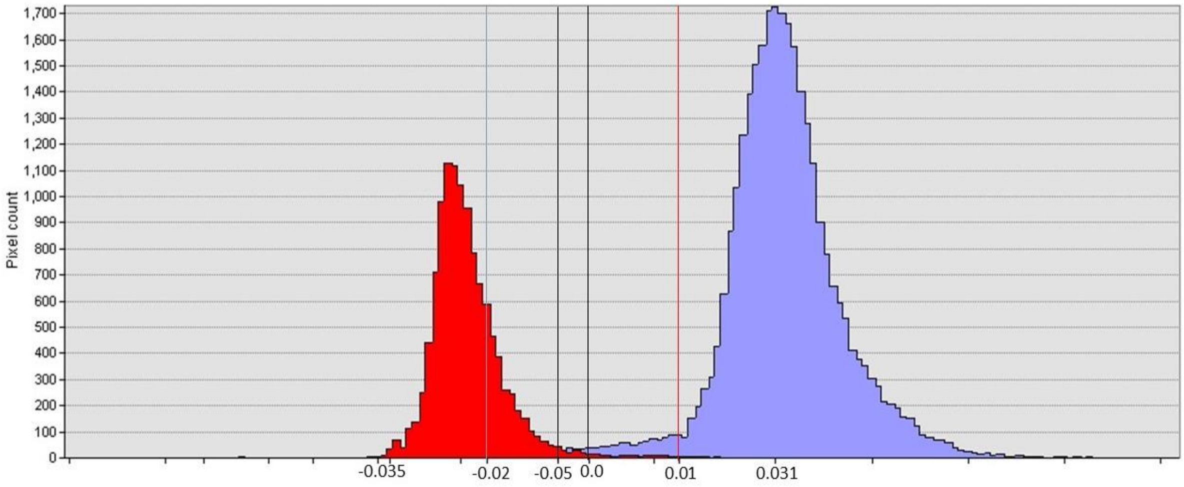

Figure 7. Frequency distribution of NDVI values for the off-road track (red) and grassland area (blue). A clear distinction is seen between the two areas, indicating that surface conditions are different at those two sites with the off-road track area more degraded in general. Mean NDVI value was -0.05 and affected areas from off-road tracks was between the -0.02 to 0.01 in the study area.

Combining the results of NDVI frequency of vegetated area and degraded area of study area, resulted in suggesting that the affected values of degradation lay between -0.02 to 0.01, and the mean was -0.05 of NDVI analysis in the study area. On the NDVI map, -0.094 indicates extended road and is included in selected values.

The cross-section transects of NDVI of off-road track (see Fig.1) results are shown in Fig. 10. A total of 28 transects were established in 5 off-road tracks in the study area. The lowest NDVI values were found at the tracks (-0.094), but increased with distance. Keshkata et al. (2012) mentioned about 11000 km of the total road network as affected in the 3260 km^2 area being lost to degradation caused by off-road track corridors, corresponding to an average width of 164 m. Myagmartseren (2012) found that dust emission from off-road track was affecting land 50 to 200 m from the track in arid areas in southern Mongolia. This result provided negative NDVI values from trend analysis of off-road track and was well-evaluated.

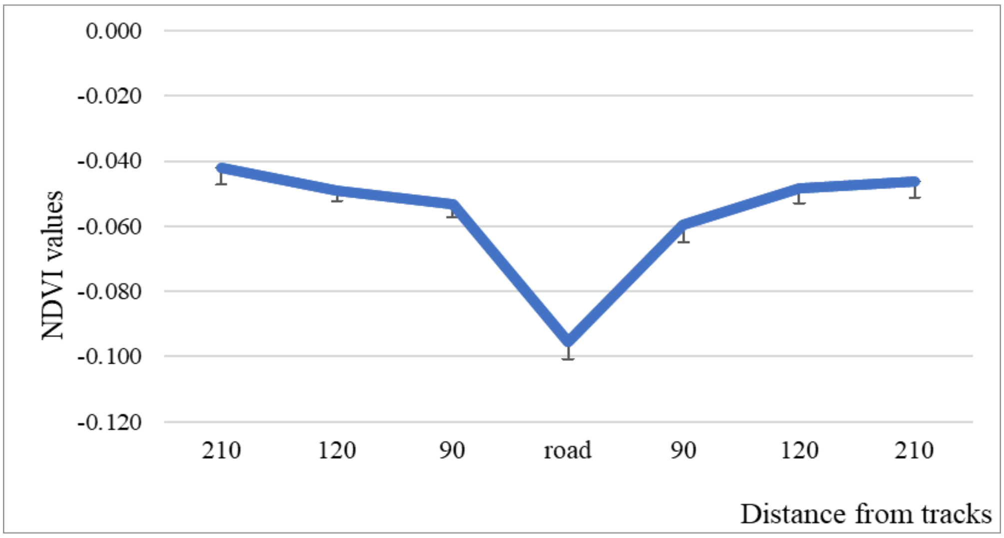

Figure 8. Average NDVI transect values (n=30) from off-road tracks in both the Gurvantes town area and the mining area. A clear trend was observed with increasing distance, suggesting that the tracks are indeed a source of land degradation in their surrounding areas. The error bars indicate the standard deviation (SD) of the mean - only lower part of the SD is shown.

3.3 Change in soil surface levels

The off-road track simulation experiment was conducted to identify the local impact of tracks on their environment. It revealed that the soil surface level decreased with number of runs (Fig. 11) and bulk density increased linearly with the number of runs. Table 2 lists three additional observed key soil factors that changed during the simulation experiment; soil organic matter, bulk density and soil erosion. The result shows that the organic matter had decreased 30% and bulk density was increased 25% in the topsoil, respectively (Table 1). Li et al. (2004) and Li and Lindstrom (2001) concluded that intensive tillage led to soil erosion, as evidenced by the organic matter and surface changes on cultivated slopes in the Chinese Loess Plateau.

The effect of operation runs on soil surface changes varied, depending on the number of runs. Little erosion was observed after the first 10 runs, but after 30 runs a loss of 2.0 cm was observed and a stable decrease of 0.4 cm (max 0.8 cm, min 0.1) for 31 to 50 operation runs.

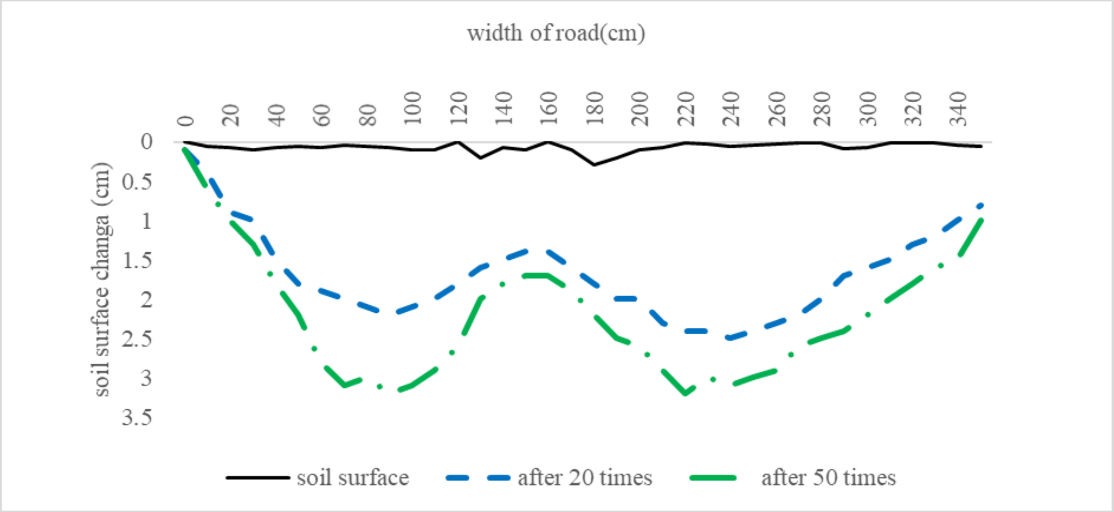

Figure 9. Soil surface changes in the track experiment.

Table 1. Observed changes in soil properties during the simulated track experiment.

Depth cm	OM %	Bulk density (g/cm^3)	Soil erosion t/ha
Before operation			
0-10	0.751	1.35	0
10-25	0.613	1.58	-
25-40	0.576	2.44	-
After 50 operations			
0-10	0.588	1.66	300
10-25	0.370	2.12	-
25-40	0.506	2.73	-
Change	-0.078	+0.38	300

4. DISCUSSION

The soil surface changes and organic matter decreases in the present study show that soil erosion occurs at off-road tracks, and this is in agreement with previously published studies (e.g. Batkhishig 2016; Kato et al. 2004; Mandakh et al. 2016). The soil erosion rates observed here were in the range of 300 t/ha. Batkhishig et al. (2008), who used fallout radionuclide isotopes to assess soil erosion in grassland in central Mongolia, estimated soil erosion rates to be between 4.0 to 6.0 t/ha. Qi et al. (2010) suggested that the wind erosion rate varied from 64.5 to 419.6 t/ha along the transect between Mongolia and Inner Mongolia and that high intensity of population and human activity may be responsible for more severe wind erosion. Mandakh et al. (2016), using a modelling approach, predicted highest erosion values in the range of 15-20 t/ha in the Mongolian Gobi region. Kato et al. (2004) estimated soil erosion and desertification in eastern Mongolia, using isotopes (^{137}Cs and ^{210}Pb). His results indicated that erosion rates were from 0.4 to 2.6 t/ha/yr. The results presented here are higher, except for Qi et al. (2010), underlining how serious an erosion source the off-road tracks can be.

In this study, the decline in organic matter in the track experiment was attributed to soil loss by wheels (Table 1). Li et al. (2000) reported a positive relationship between soil nutrients and the soil redistribution rate from the intensive tillage system, suggesting also the effect of erosion in nutrient depletion, as this study showed. Total available nutrients have been shown to have a negative relationship with tillage intensity (Bork and Li 2004).

The increase in soil bulk density is evidence of surface soil loss and exposure of the subsoil horizon (Webb et al. 1983; Byambaa and Muryami 2012). The bulk density increased with runs; after 50 runs, it had increased from 1.35 g/cm^3 to 1.6 g/cm^3 and from 2.1 g/cm^3 to 2.4 g/cm^3 in the 0-5 cm and 10-20 cm horizons, respectively. Shen et al. (2004), who were studying vegetation dynamics of abandoned off-road tracks in eastern Mongolia, suggested that soil compaction was one of the main restrictions of root development and re-vegetation. They found that surface strength was 4 times higher in abandoned roads and 150 times higher in intensively used off-road tracks, suggesting a corresponding change in BD. More recent studies suggest that bulk densities may be up to 10 times higher in off-road tracks in southern Mongolia than in adjacent control areas (Byambabayar 2017).

Several studies have used NDVI analysis to assess land cover change and land degradation in Mongolia (Munkhnasan et al. 2015; Iwasaki 2006), but few have assessed off-road track-related degradation. Our results indicated by NDVI values varied depending on distances from off-road tracks and it must be assumed that the NDVI captured vegetation degradation driven by off-road track erosion (Fig.8). This showed that off-road track area is a serious source of land degradation in the arid ecosystems of southern Mongolia.

5. CONCLUSION

Based on the results, it can be concluded that tracks are a source of land degradation in southern Mongolia on a large scale. On smaller scales, there are also noticeable negative impacts on the environment such as considerable erosion, increase in bulk density and loss of soil organic matter. These are serious environmental problems that need attention.

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