Merging remote and in-situ land degradation indicators in soil erosion control system

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Abstract

The objectives. To determine the land degradation indicators based on satellite and in-situ data for soil erosion assessing and monitoring. **Methods.** The logical model of soil erosion detection and assessment is developed, based on the plane and gully erosion identification by merging the high-spatial resolution Earth observation and in-situ data. The Landsat 8, RapidEye, Sentinel 1,2 satellite data, map materials and data of ground observations were used for erosion identification. The plane soil erosion was determined by humus content modelling using soil spectral characteristics, obtained by satellite data. The gully erosion was identified by using the decision tree, based on the land degradation indicators. **Results**. Remote and in-situ indicators of erosion degradation were developed. The gully erosion distribution within the research area was mapped based on the Sentinel 1,2 radar and multispectral data for 2016-2017. The possibility of soil water erosion assessment and classification using regression models is proved. The areas of plane soil erosion were identified by the humus content modeling using regression models of soil spectral characteristics and in-situ data

Keywords: land degradation, indicators, satellite, in-situ data, humus, gully, modelling

Introduction, scope and main objectives

Erosion degradation is one of the unresolved agricultural problems in many regions of the world, including Ukraine. In Ukraine, more than 15 million hectares of agricultural land are affected by water erosion, that is more than half of arable land. The annual rate of washing away of highly fertile topsoil reaches the 15-20 tonnes ha^{-1} yr^{-1} in some years due to water erosion, and the area of eroded lands is increasing annually by 100 thousand hectares. In Ukraine, the negative trends of land degradation and desertification, as well as soil fertility depletion are getting deeper, and in recent decades have become a global problem, targeting the agricultural lands in all natural and climatic zones. Along with land erosion degradation there is dehumidification of soils, which negatively affects not only the nutritional soil regime, but also its biodiversity and anti-erosion stability.

Soil erosion poses a major threat to global food security and to the achievement of the Sustainable Development Goals, especially Target 15.3: "By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world" (UN, 2015).

To monitor the implementation of Target 15.3, an indicator "The ratio of the degraded land area to the total land area" was adopted. (*Report of the Inter-Agency and Expert Group on Sustainable Development Goal Indicators 2016*).

Traditionally, aerospace materials were used in conjunction with ground-based observations to detect soil erosion or to obtain input data for its simulation, but with the development of space-based systems of high spatial resolution, satellite images have become widely used. The use of multi and hyperspectral remote sensing systems, combining various remote sensing data (Metternicht, Zinck, 1998), ground data (Mathieu *et al*., 2007) and models (De Jong *et al*., 1999) makes it possible to obtain quantitative characteristics of spectral reflection and radiation for automated classification of eroded lands and soil erosion mapping in agricultural landscapes.

With current availability of high spatial resolution satellite images it becomes possible to identify the spatial distribution of eroded soils and gully systems. That causes the necessitates for the identification of complex erosive degradation indicators, development and testing of water erosion classification models based on multispectral satellite images of high spatial resolution.

Thus the creation of up-to-date soil erosion control system using the data of the Earth's remote sensing becomes urgent. The actual aim is the development of modern indicators for this system to determine the soil erosion and assess the area of degradated land.

Methods

Soil erosion indication with remote sensing data is related to the assessment of the erosion determinants, which include soil properties, vegetation, topography and the land use type. The method of integrated assessment of land degradation using GIS / RS technologies is based on the integrated index of soil erosion degradation, which is used for land degradation mapping. This index is calculated by three main characteristics: the land degradation type, spatial extent and rate. To assess the extent and rate of degradation, the relevant model is used in accordance with the type of degradation. Two types of water erosion are considered in this study: plane and gully erosion.

Gully erosion is the most rapidly evolving form of erosion. One of the most important aspect of its monitoring, is the analysis of the conditions of its formation, which could be divided into following groups: landscape relief, climate, geological structure, soil conditions, vegetation cover. This gully formation conditions are used for the development of gully erosion indicators and geospatial models using satellite data to determinate the erosion manifestations and predict the risk of its development. For gully development risk modeling, we developed a decision tree based on the determined indicators of gully erosion (Figure 1). This method allows to carry out the classification of gully objects on satellite images without the prior in-situ data collection on the basis of defined conditions in the form of a decision tree (D'Oleire-Oltmanns *et al*., 2014, Shruthi *et al*., 2011). In-situ data in this case is used to validate the simulation results.

Another type of water soil erosion is *plane erosion*. The spectral brightness of soil reflects the humus content. When the upper genetic horizons of the soil are washed out, the humus content in topsoils decreases accordingly, which leads to the changes in soil spectral characteristics. The detection of these changes makes it possible to estimate the spatial and temporal intensity of erosion processes.

The classification of soil erosion rates by the remote sensing data is based on the integrated use of space-based data of high spatial resolution and supporting thematic information on soil cover characteristics (spectral, agrochemical).

Quantitative characteristics of spectral reflection and radiation make it possible to apply an automated classification of eroded lands based on the ground-based calibration data. The correlation between spectral brightness and humus content is analyzed using satellite image and in-situ sampling data for different soil classes. At each sampling point, the values of the spectral brightness in all spectral bands of satellite image are derived and humus content is determined in the laboratory.

There are two approaches for plane erosion detection using satellite data connected to the soil surface conditions. The first approach is based on the analysis of soil spectral characteristics to assess the changes in humus content. The erosion rate is determined by the mathematical-statistical modeling of the humus content as an indicator of plane erosion. Required stages are the validation of multiply regression models and mapping of spatial distribution of plane erosion within homogeneous regions. The second approach is based on the analysis of spectral vegetation characteristics to assess the vegetation condition as an indicator of soil fertility (Petrychenko *et al*., 2014).

Results

The research was carried out in Kanivsky district of Cherkasy region and Myronivsky district of Kyiv region, as the typical area of agricultural landscapes of the Central Forest-steppe climatic zone. There is a high risk of soil erosion in the study area, in particular the gully development, due to the complex relief. The raster layers for each indicator were derived from satellite data. The indicator of the relief impact, in particular the index of length and slope steepness was calculated based on the elevation model of the study area. The land use type impact was determined on the basis of land cover map, derived by Landsat-8 and Sentinel-1,2 image processing. The following land cover classes were allocated: forest, forest bands, herbal vegetation, agricultural lands. For each class, an indicator of the level of favorable development of erosion was determined.

On Figure 1 the decision tree, developed based on the proposed soil erosion indicators, is demonstrated. The decision tree could be applied in random forest classification method in GoogleEarthEngine environment.

The next stage was model validation for gully erosion detection using ground investigations, and a final map of the gully erosion formation in Kanivsky and Mironivsky regions was obtained (Figure 2).

Plane soil erosion detection was carried out within the mask of arable lands, divided into homogeneous areas in terms of soil type, slope and slope exposure. Five homogeneous by optical characteristics soil classes were identified: dark grey soils, grey sandy loam soil, dark grey light loam soils, black typical low-humus soils, black typical light loam soils.

The correlation between spectral brightness and humus content was analyzed using Landsat satellite image and in-situ sampling data for different soil classes.

The correlation coefficient of spectral brightness, vegetation indices and percentage of humus was quite high, ranging from 0.42 for gray sandy loam soils to 0.78 for dark gray soils and black regressed light loam. As a result, the multiple regression equations of the dependence between the values of humus content as depended variable and the spectral brightness of different spectral bands of Landsat 8 image (R1-8) were obtained by the linear multiple regression method:

1) for dark gray and black soils regressed light loam

$$H = 1.95+1.21\times R1+2.55*R2-1.15*R3-3.26*R4+1.25*R5+1.67*R6-0.44*R7-0.58*R8,$$

2) dark grey light loam

$$H=1.07-6.54*R1+0.73*R2-0.71*R3+1.87*R4+10.83*R5+0.26*R6-3.05*R7+0.84*R8$$

3) grey sandy loam

$$H=-1.7-13.72*R1+3.3*R2+5.78*R3+8.79*R4+6.12*R5+8.21*R6-0.69*R7-0.16*R8$$

4) black soils typical little humus

$$H=-3.37-2.49*R1+80.92*R2+16.37*R3-22.27*R4+3.96*R5+1.9*R6-12.42*R7+2.03*R8$$

5) black soils typical light loam

$H=0.4+0.19*R1+0.93*R2+0.14*R3+0.56*R4+4.52*R5+0.39*R6+1.25*R7-0.32*R8$;

6) black soils typical little humus, covered by winter wheat (by RapidEye image)

$H=0.16343*BI - 0.00044*BI^2 - 0.30913*BIRE + 0.00074*BIRE^2 + 18.68743$,

where

H – humus, Ri – spectral bands, $BI=sqrt((R2^2 +R3^2)/2)$, $BIRE=sqrt((R2^2 +R4^2)/2)$.

Average relative error of the model is 14.8 %, calculated by the comparative analysis of modeled humus content and soil samples data, which were not included in multiple regression model.

The spatial distribution of soil erosion degradation was assessed based on the ratio of eroded lands in the region. Up to 9.8 % of the territory of Kanivsky region are considered to be highly eroded lands, resulting in more than 20 tonnes ha^{-1} yr^{-1} of soil loss, and up to 1.9 % in Myronivsky region. The results may be used for the development of land conservation plans.

Discussion

The main objective of the study was to demonstrate the possibility of combining in-situ and satellite data to obtain the soil degradation indicators and use it in erosion control.

The increase of extreme rainfall, growth of cultivated crops areas, lack of the anti-erosion measures, degradation of field-protecting forest bands create the conditions for the development of catastrophic erosion processes. Thus, the results of feasibility study on integrated use of remote and in-situ indicators of gully and plane erosion are highly important.

Conclusions

The use of up-to-date remote sensing and geoinformation technologies enables to obtain the accurate and up-to-date information on the state of soil cover at various spatial levels. The decision tree for logical model of soil erosion determination and assessing, based on the merging of remote sensing data of high spatial resolution with in-situ data is proposed. The possibility of soil water erosion assessment and classification using regression models is proved with the accuracy of 85 %. The results of erosion process risk assessment using remote sensing are the basis for the planning and implementation of the anti-erosion measures to optimize the structure of agricultural landscapes and land use systems.

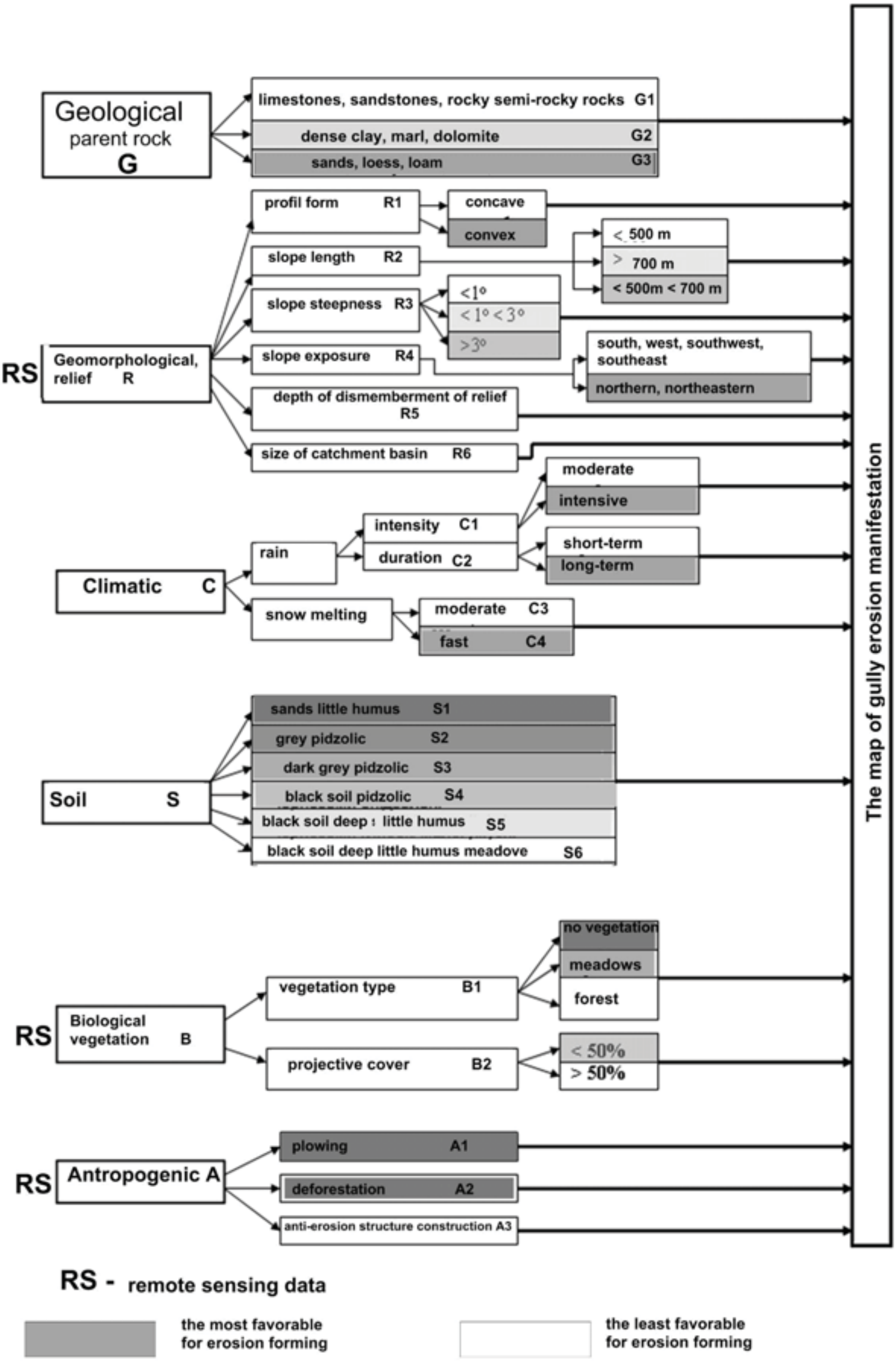

Figure 1: Indicators of the gully erosion formation

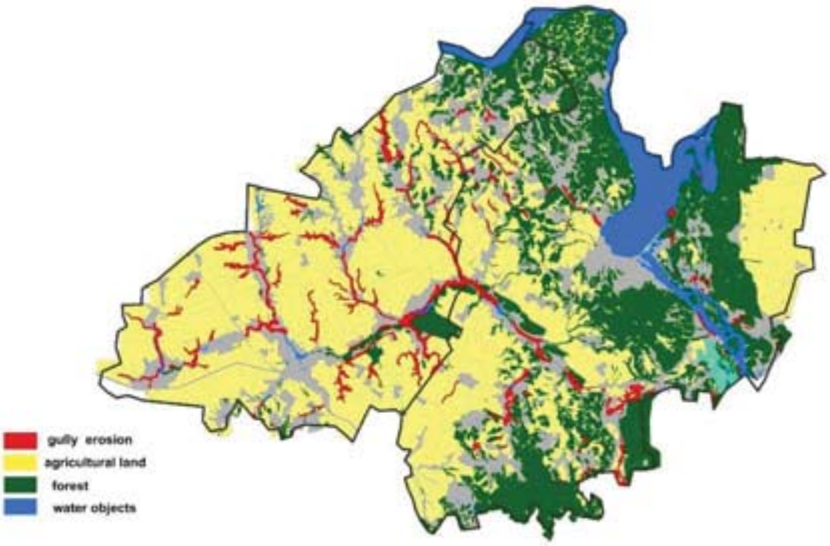

Figure 2: Map of the gully erosion formation in Kanivsky and Myronivsky regions

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