Soil dynamics estimation using Landsat data in Saratov Povolzhye region (Russia)

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Abstract. Soil undoubtedly plays an important role in agricultural production. However**,** negative tendencies in the soil formation processes of arable lands (dehumification, salinization, wind and water erosion, acidation) can be widely observed nowadays. Moreover, there is a lack of up-to-date information about occurred changes in arable soil cover. Therefore, it is necessary to develop an approach that will allow accurate and timely assessment of soil properties dynamics. The presented research deals with the application of satellite data for estimating the soil properties dynamics of arable soil cover by the example of the test plot in Saratov Povolzhye region. Suggested approach relies on the soil line concept (Richardson, Wiegand, 1977) and on the relationship between the soil line parameters and soil characteristics. It enables to perform per pixel analysis of soil cover, to mark out the plots where sharp or gradual changes in soil properties took place as well as to assess the general direction of those changes (trend presence estimation by the Foster-Stuart method). The important result of the developed approach application is the map of soil cover dynamics of the test plot for recent 30 years developed after the analysis of 17 Landsat TM 5 scenes from 1984 up to 2010.

Key words: Soil properties, Satellite data, Soil line concept, Foster-Stuart method

1. Introduction

Information about soil cover is considered to be of great importance to agricultural production. Soil properties determine cultivated crop range, farming techniques, as well as farm production quality. Taking into account soil characteristics one enables to perform both economically- and ecologically-wise agricultural production.

Currently soil maps are known to be the main source of soil data. It should be pointed out that the existing soil maps in the Russian Federation have become obsolete as they have not been updated during the last 30 years. Consequently there is a lack of information about soil cover changes which have occurred recently. Meanwhile the issue of soil dynamics assessment, especially concerning arable lands, is very urgent nowadays due to soil degradation processes (water and wind erosion, dehumification, salinization, acidation).

Recently developed remote sensing techniques and increased satellite data availability (including archive information) provide new promising possibilities for dealing with the problems of both digital soil mapping and soil monitoring.

Therefore, the aim of our research is to develop the method for analysis of soil cover dynamic using remote sensing information. Landsat data was chosen for the study because there is a continuous archive of satellite information from the year of 1982 till present days.

2. Methodology

2.1 Study site

To carry out the research the test plot located in Saratov Povolzhye region of the Russian Federation was selected. Total plot area amounts to 9280 ha. The study site occupies southern part of the forest-steppe zone. Concerning relief, research area lies on the High Don Plain on the common watershed of two rivers such as Hoper and Medveditsa. The general terrain character is mainly undulating.

Soils are mainly represented by automorphic and semi-hydromorphic chernozems of various granulometric composition (from sandy to heavy clay soils). There are also several fields where cheznozems form combinations with solonetz-like soils. Humus content of test soils vary from 4 up to 8 %.

As to the negative tendencies in the soil genesis processes one should mention that area is subjected to rainsheet erosion which causes the formation of slightly and moderately eroded soils. There is also soil compaction problem in this region.

2.2. The soil line concept

The research is based on the soil line concept developed by Richardson and Wiegand (1977). According to that concept the soil line is a linear relationship between the reflectances of bare soil surface in NIR and Red spectral bands (Equation 1, Figure 1).

$$NIR=\beta_1 R+\beta_0, \quad (1)$$

where β_1 - slope and β_0 - intercept.

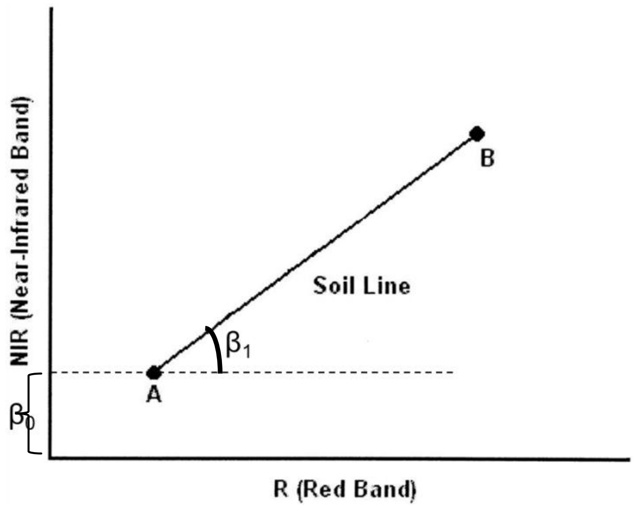

Figure 1. The graph of the soil line (Richardson and Wiegand, 1977)

Originally the soil line was mainly used in the evaluation of vegetation cover to minimize an effect of soil background on vegetation indexes. According to (Karmanov, 1970, Savin, 1997, Orlov, 2001) there are two possible ways of how soil can influence the performance of a soil line. Soil brightness that is affected by soil moisture or soil surface roughness is known to be the first interfering factor. The important point is that the variation in this characteristic doesn’t change the soil line parameters (Figure 2).

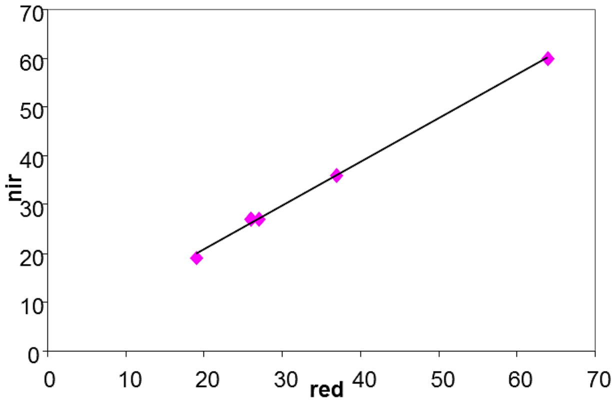

Figure 2. The behavior of the soil line parameters in case of soil brightness changes (Kirianova, Savin, 2011)

The second factor is connected with properties determining the soil color (humus type and content, mineral constituents of parent material, soil erodibility). Changes in such properties result in the variation of the soil line parameters (Figure 3). The dynamics of this group of soil properties was the main focus of our research.

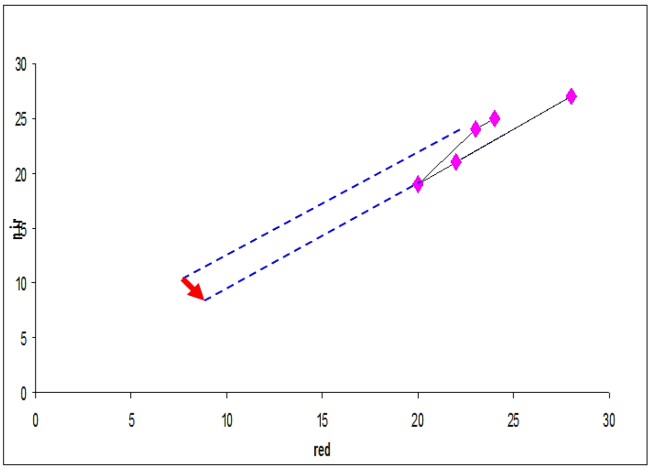

Figure 3. The behavior of the soil line parameters in case of soil color changes (Kirianova, Savin, 2011)

2.3 General or individual soil line

Richarsond and Wieagnd considered the existence of the general soil line. Huete and others (1984) obtained the general soil line for 20 soil types, Galvao and Vitorello (1988) for 14 soil types.

However, according to Baret (1993), it is impossible to develop the global soil line characterizing all the soil types as such a line will be linear only at some its parts due to the variations caused by different soil characteristics. Moreover, the discrepancy between the general soil line and the true soil line will cause errors when using the soil line to determine properties of both vegetation and soil cover (Heute, Yoshioka, 2010).

Taking this fact into account, in the framework of our research the soil line is determined at a pixel level.

2.4 Soil changes identification

Generally, the performed analysis comprises the following main steps. Firstly, it was necessary to identify the pixels that belong to bare soil surface. A number of vegetation indexes including NDVI, RVI, NRVI and TTVI (Jordan, 1969; Rouse et al., 1973, Baret and Guyot, 1991; Thiam, 1997) was used to distinguish between bare soil and other background components (vegetation, water bodies, roads, buildings).

The threshold value range, characterizing bare soil surface, were developed for each above-mentioned index (Table 1) based on the representative sample of 250 points, that are very likely to represent bare surface. The points were selected from 17 images of Landsat TM 5 (1984-2010 years).

Table1. Value ranges of vegetation indexes characterizing bare soil surface

Index	Calculation equation	Bare soil surface
NDVI	(NIR-RED)/(NIR+RED)	-0,04673-0,05882

RVI	RED/NIR	0,88889-1,09804
NRVI	(RVI-1)/(RVI+1)	-0,05882-0,04673
TTVI	(√abs{(NIR-RED)/(NIR+RED}+0,5	0,68041-0,74755

Obtained value ranges were then used to design a map of bare soil surface for arable lands of the test plot for each selected Landsat TM 5 image.

At the next step, the slope of the soil line was calculated for pixels belonging to bare soil. Temporal changes in the soil line slope are considered to be the indicators of temporal changes in soil properties.

To assess the character of the occurred changes as well as their direction and the trend existence, the method of Foster-Stuart was used along with some other statistical parameters (Dybrova, 2004).

It is should be mentioned that satellite data processing is performed with ILWIS 3.3. Academic.

3. Results and discussion

The fragments of the map of bare soil and the map of soil line slopes are given below (Figure 4, Figure 5).

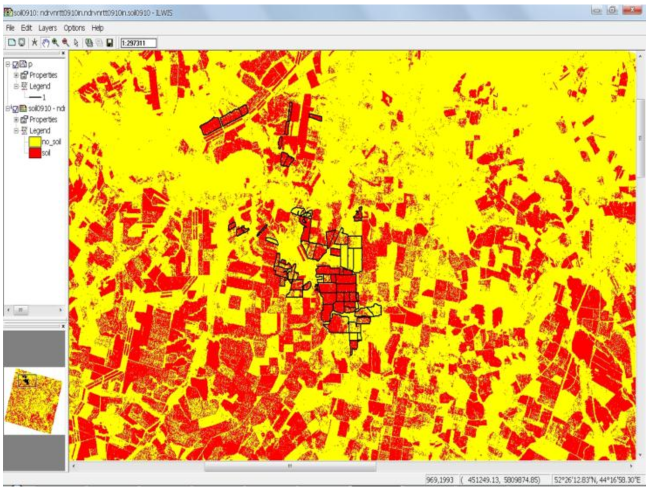

Figure 4. The fragment of the map of bare soil (in red) obtained for Landsat 5 TM image from 09.09.2010

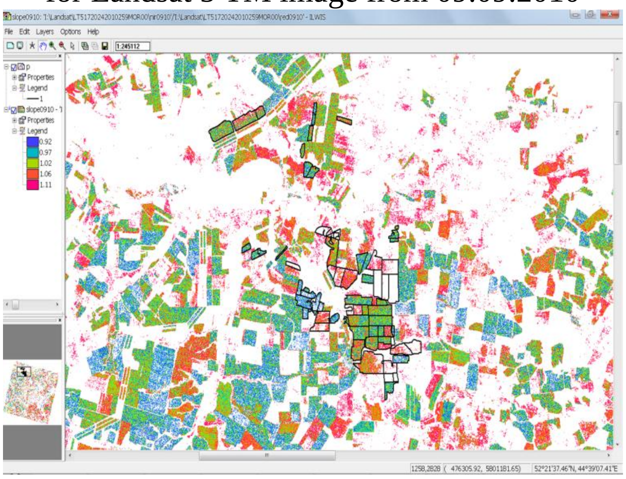

Figure 5. The fragment of the map of the soil line slope obtained for Landsat 5 TM image from 09.09.2010 (different colors indicate different soil lines)

The map of average slope values was also developed to assess the spatial variations in soil cover (Figure 6). Soils of low humus content as a rule are characterized by higher slope values. Soils with high humus content have minimal slope values.

Figure 6. The fragment of the map of average slope values

To evaluate the statistical liability of soil line slope, it was necessary to assess the trend presence. To perform such an evaluation Foster-Stuart method was used. The obtained trend map is given below (Figure 7).

Figure 7. The fragment of the trend map of the test area (plots where any statistically valuable trend in slope change is observed are marked with purple color)

The map of standard deviations of soil line slopes was produced as well (Figure 8). It helps to understand arable soil cover heterogeneity as such a map enables both to determine the plots which are characterized by insignificant changes in slope values and to mark the plots with sharp variations in this parameter. An increase in the range of slope value variations can be explained by the heterogeneity of soil cover resulted from agricultural practices for example uneven application of fertilizers.

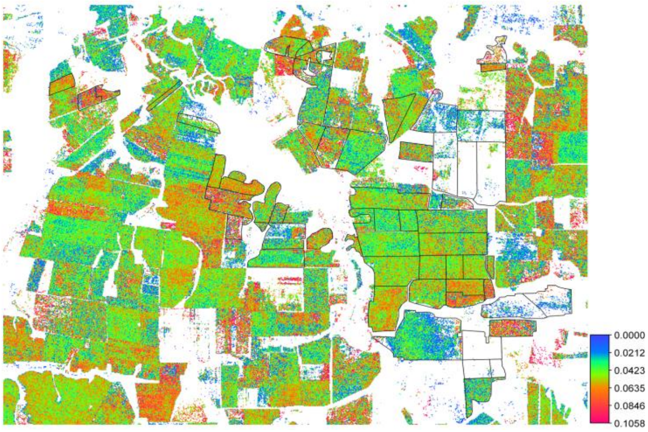

Figure 8. The fragment of the map of standard deviations of soil line slopes

To take into account one-time slope changes the rule was applied that states that if an average value of slope exceeds 2-sigma interval, it indicates sharp changes in soil properties. Very few pixels of the test plot met this condition (Figure 9). Thus, occurred changes in soil properties of the research area are mainly gradual and directed.

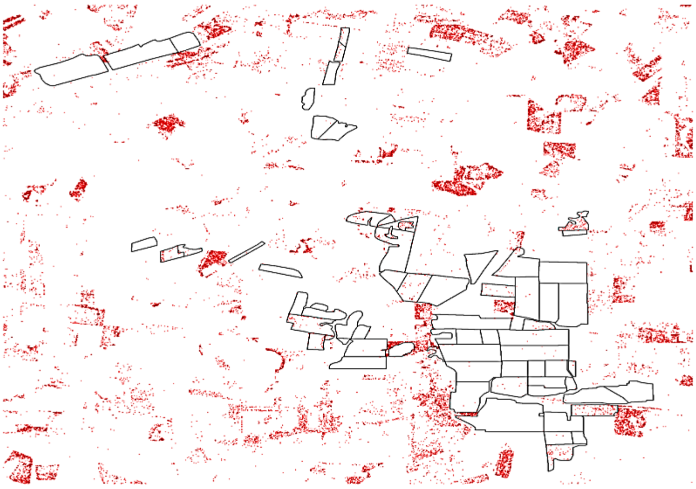

Figure 9. The map of sharp changes in the soil line slope
(plots where sharp changes took place are marked with red color)

The main result of the performed research is the map of soil cover dynamics of the test plot for recent 30 years (Figure 10).

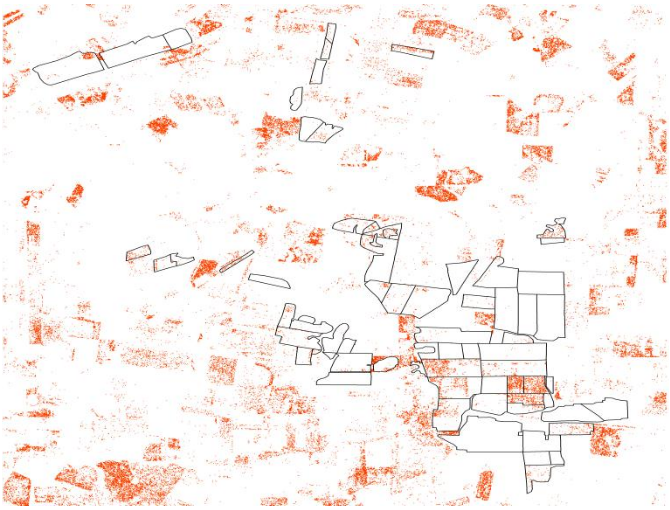

Figure 10. The fragment of the map of soil cover dynamics of the test plot for recent 30 years (the plots where any type of soil properties dynamic is observed are marked with red color)

4. Conclusions

Developed approach allows to mark the plots where sharp or gradual changes in soil properties took place and assess the general direction of such changes.

However, further research is needed to identify the relationship between changes in certain properties and changes in the soil line parameters as soil reflectance is influenced by a variety of soil properties. That will enable to turn from the general dynamics evaluation to the assessment of the dynamics of specific soil properties.

It is also should be mentioned that presented approach can yield accurate results only if it is applied for soils of arable lands.

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