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Technical Note

Detection of Changes in Arable Chernozemic Soil Health Based on Landsat TM Archive Data

Igor Savin [1,2,3,*], Elena Prudnikova [1,3], Yury Chendev [2], Anastasia Bek [2], Dmitry Kucher [1] and Petr Dokukin [1]

[1] Department of System Ecology, Peoples Friendship University of Russia (RUDN University), Moscow 117198, Russia; prudnikova_eyu@esoil.ru (E.P.); kucher-de@rudn.ru (D.K.); dokukin-pa@rudn.ru (P.D.)
[2] Department of Land Use and Land Cadaster, Belgorod State University, Belgorod 308015, Russia; Chendev@bsu.edu.ru (Y.C.); 966665@bsu.edu.ru (A.B.)
[3] V.V. Dokuchaev Soil Science Institute, Department of Soil Geography, Moscow 117019, Russia
* Correspondence: savin_iyu@esoil.ru

Abstract: When soils are used for a long period of time as arable land, their properties change. This can lead to soil degradation and loss of fertility, as well as other important soil biosphere functions. Obtaining data on the trends in arable soil conditions over large areas using traditional field survey methods is expensive and time-consuming. Currently, there are large archives of satellite data that can be used to monitor the status of arable soils. The analysis of changes in the color of the surface of arable chernozem soils of the Belgorod region, for the period from 1985 to the present, has been carried out based on the analysis of Landsat TM5 satellite data and information about the spectral reflectance of the soils of the region. It is found that, on most parts of arable lands of the region, the color of the soil surface has not changed significantly since 1985. Color changes were revealed on 11% of the analyzed area. The greatest changes are connected with the humus content and moisture content of soils. The three most probable reasons for the change of humus content in an arable horizon of soils are as follows: the dehumidification of soils during plowing; the reduction of the humus content due to water erosion; and the increase in humus content due to changes in the land-use system of the region in recent years. The change in soil moisture regime has mainly been found in arable lands in river valleys, most likely conditioned by the natural evolution of soils. Trends of increasing soil moisture are prevalent. The revealed regularities testify to the high stability of arable soils in the region during the last few decades.

Keywords: soil degradation; Landsat; chernozems; soil erosion; dehumidification

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1. Introduction

Chernozemic soils have the highest natural fertility of all soils in the world. Cultivated crops can often be produced on chernozems without the need for fertilizers [1]. For this reason, most of the chernozemic soils in the world are currently plowed. For example, Russia has more than 50% of the world's chernozems [2], more than 73% of which are plowed, and they cover about 54% of the country's arable land [3]. However, the productivity of the chernozem soils strongly depends on their health and status. The degradation of soils quickly leads to a loss of their high natural productivity [4].

Chernozemic soils have been involved in plowing for over 200 years. As a result, the properties of many chernozems have changed significantly [5,6] and continue to change depending on their specific use. Thus, according to ISRIC [7], about 23% of chernozem soils in the world are already degraded to some extent. In Russia, most of the arable chernozem soils are eroded, while some are compacted and subjected to secondary salinization [8]. Degradation leads to a significant decrease in the fertility of chernozems and also reduces the ecological value of soils, decreasing their ability to purify water and the surface air layer, reducing the importance of soils as a component of biosphere stability [9]. In addition, the arable horizon of chernozems, having a high buffer capacity, is capable of absorbing more pollutants (heavy metals, radionuclides) than other soils, contributing to the purification of the biosphere and maintaining its resistance to anthropogenic impact [10].

Chernozems accumulate most of the carbon contained in the mineral soils of the world [11]. Therefore, the degradation of chernozems leads to the disruption of carbon cycles in the Earth's biosphere. Moreover, through the introduction of special technologies for the use of chernozems, it is possible to force the absorption of carbon dioxide by these soils from the atmosphere, thus influencing climate change [12].

Thus, the degradation of chernozems leads to loss of their main soil functions, and consequently, to the deterioration of soil health. Different organizations use different definitions of term "soil health". The United States Department of Agriculture's Natural Resources Conservation Service defines soil health as "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and humans" [13].

The Intergovernmental Technical Panel on Soils (ITPS) of FAO defines soil health as "the ability of the soil to sustain the productivity, diversity, and environmental services of terrestrial ecosystems" [14].

One of the complexities in defining soil health is the lack of agreement on indicators and threshold values due to the singularities and high spatial variability of global soils.

Soil degradation status is one of the integral indicators of soil health. From this point of view, we treat changes of arable soils, which deteriorate one of the main soil functions, namely productivity, as processes which affect arable soil health.

To prevent further deterioration of the quality of chernozem soils, it is necessary to obtain objective and prompt information about their status. The existing system used to monitor arable soils in Russia [15] is unable to provide such information due to various reasons (lack of funding, outdated methodological approaches, high labor intensity of obtaining primary information, lack of qualified personnel).

The possibility of using satellite data for the rapid gathering of information on arable soils' status looks promising. Currently, there are already several developments in this direction [16]. Sufficiently long satellite data archives have already been accumulated to detect dynamic changes in soil and soil cover. For example, the archive of comparable global Landsat data has existed since 1984 to the present with a time step of 15 days. Experience has been accumulated in detecting temporal changes in land cover and soils based on the analysis of multitemporal satellite images [3,17].

All of these factors create a good basis for prompt and objective analysis of soil dynamics in recent decades. A few researches so far have undertaken studies in this direction, especially for large areas. The authors of this article have experience in the interpretation of satellite information with regard to the identification of different features of soils, soil cover, and terrestrial water storage at the territory of the administrative boundaries of the Belgorod region in southwest Russia [18,19].

The aim of the research is to study the trends in the properties of arable chernozem soils in the Belgorod region of Russia, based on the analysis of multitemporal Landsat TM5 satellite data and information on the spectral reflectance of the region's soils.

For this purpose, a comparative analysis of satellite images obtained using the same sensor at the same imaging time in different years was carried out. The database on spectral reflectance of soils in the region and expert knowledge of the peculiarities of its change during the degradation of chernozems were used as the basis for deciphering changes in the images of the open surface of arable soils revealed by satellite data.

2. Materials and Methods

2.1. Study Area

The Belgorod region is situated in the southwestern part of European Russia (Figure 1). It specializes in agricultural production, and over 52% of its land is plowed [20]. The average age of plowing is close to 250 years [6]. Annual cereals (wheat, barley), corn, sunflower, and sugar beet are mainly cultivated. At the beginning of the current century, the regional administration took a policy of greening agriculture and introducing adaptive landscape farming systems [21]. This led to an increase in the share of annual and perennial grasses in the composition of crops and a decrease in tilled crops, which may have affected the decrease in agrogenic pressure on the soils of arable lands in recent years.

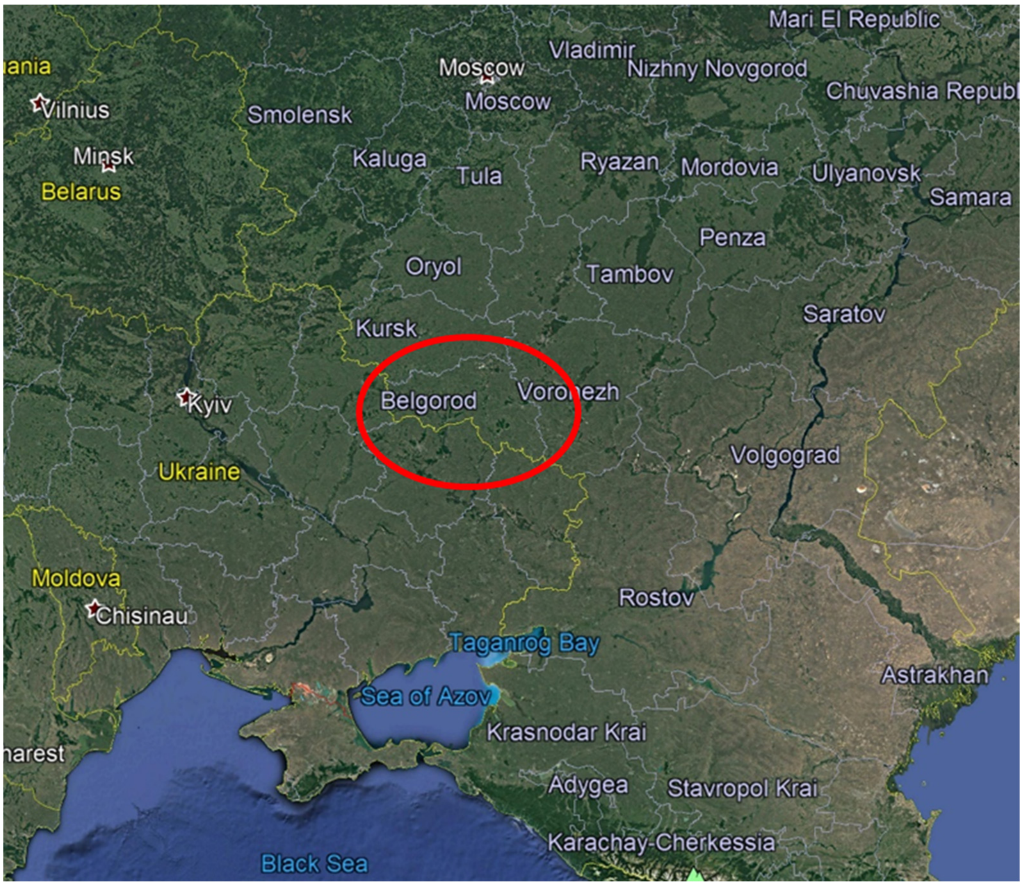

Figure 1. Geographical position of the study area (red oval).

Different variants of chernozemic soils prevail in the soil cover of the region with their total area, including soils in the beam network, reaching 77% of the total area of the Belgorod region [18]. On the arable land of the oblast (90% of the total area of agro-landscapes), black soils also prevail [22]. Chernozems of the oblast are characterized by the rather large thickness of the humus part of the profile (sum of horizons A1 and A1B is near 60–90 cm) and by high humus content (5–6%). Some of them are eroded to varying degrees (about 50% of the area of plowed chernozems). In addition to zonal subtypes of chernozems (leached, typical, ordinary soils), on arable lands of the region, there are residual carbonate, residual saline, ashy, meadow, and meadow-black soils. In addition to chernozem soils, dark grey forest soils, alluvial soils, and sod soils of beam bottoms are also involved in plowing [23,24].

2.2. Methods

A flowchart of the investigation is presented in Figure 2.

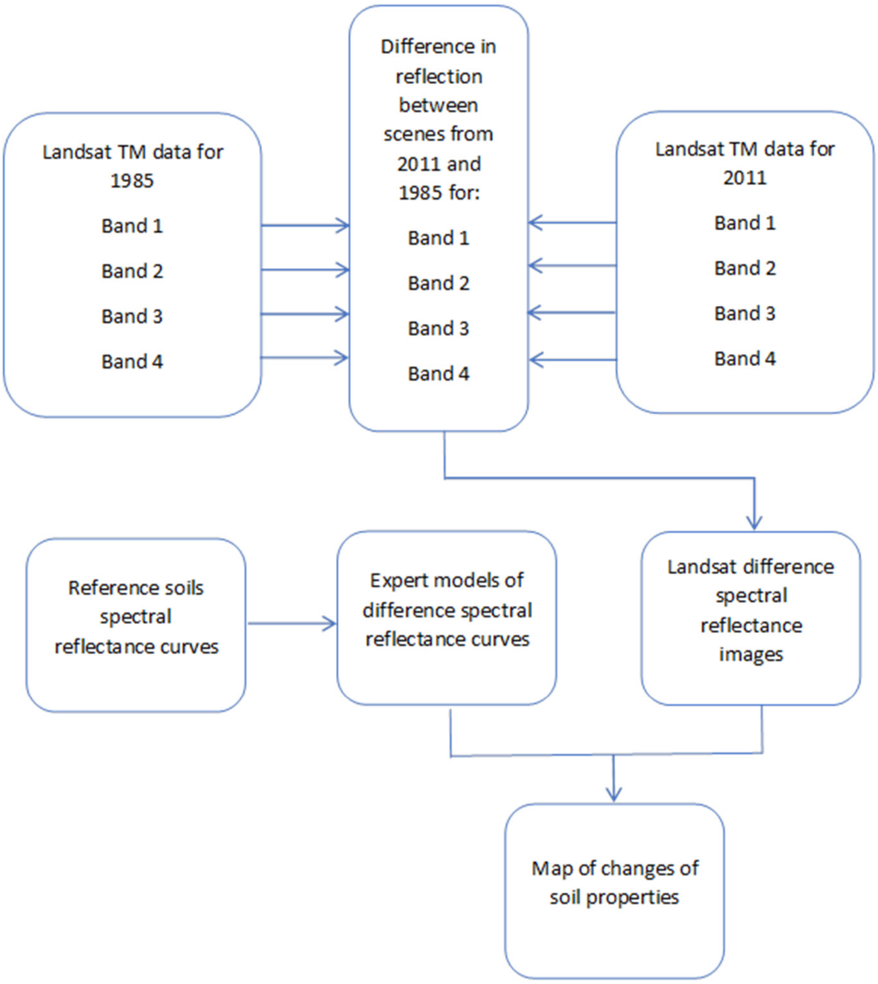

Figure 2. Flowchart of the investigation.

The analysis of changes in the color of the open surface of arable soils in the study area was carried out using Landsat TM5 satellite data, the archive of which is available from 1984 to 2011 (https://www.usgs.gov/land-resources/nli/landsat (accessed on 18 April 2021)). Data from other Landsat series sensors (e.g., OLI, which is still operational) were not used to ensure maximum comparability of images acquired at different imaging times. Based on the analysis of archived data, cloudless images covering the entire area of the region (5 scenes in total), acquired in the spring 1985 (acquired on 30 April 1985, 2 May 1985 (2 scenes), 9 May 1985, 11 May 1985) and spring 2011 (acquired on 22 April 2011 (2 scenes), 24 April 2011 (2 scenes), 3 May 2011) periods, were selected (Figure 3). Spring images were selected to obtain more pixels containing an open surface of arable soils for the analysis. We used data, atmospherically corrected based on the DOS method [25], of visible and near-infrared spectral bands (bands 1–4). After that, for each scene, the NDVI value was calculated based on standard approach (NDVI = (NIR − Red)/(NIR + Red)) [26] using Landsat TM5 imagery bands 3 and 4. Based on expert analysis of NDVI maps, a threshold value was set for each scene to allocate the pixels with an open soil surface. All pixels with vegetation were masked and excluded from further analysis. That is, only pixels containing an open soil surface in both survey periods were analyzed.

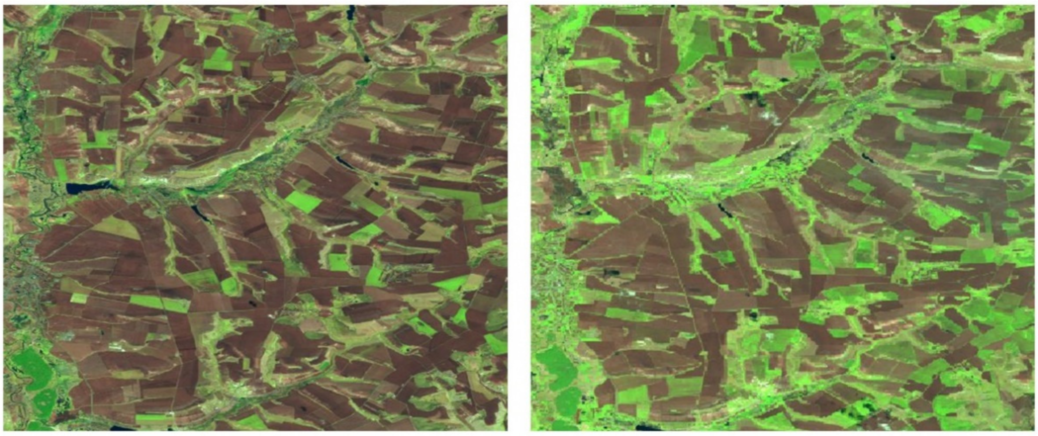

Figure 3. Examples of Landsat images (2,3,4 bands composite) for the region of research, **left**—11 May 1985, **right**—3 May 2011.

Afterwards, the difference between reflectance values for pixels with an open soil surface in 2011 and 1985 was calculated for each analyzed survey band. Difference maps of each band were classified into 5 classes: “no difference” (difference between reflectance values is less than 5%), “weak reflectance drop” (difference between reflectance values is from 5 to 20%), “strong reflectance drop” (difference between reflectance values is higher than 20%), “weak reflectance growth” (difference between reflectance values is from 5 to 20%), and “strong reflectance growth” (difference between reflectance values is higher than 20%). The difference class maps were then sequentially crossed (band 1 difference map with band 2 difference map, followed by band 3 difference map and band 4 difference map). The result is a map where each pixel is linked with attribute information about how the reflectance in each analyzed survey band has changed (for example, “no difference” in band 1, “weak reflectance growth” in band 2, “weak reflectance growth” in band 3, and “strong reflectance growth” in band 4).

This was followed by an expert analysis of all variants of detected band-by-band changes in reflectance for pixels with an open soil surface between 2011 and 1985.

For this purpose, a preliminary spectral reflectance analysis of soil samples of the research region was carried out. In total, 586 spectra of arable soils samples of the region were used. The spectra were obtained using the HandHeld-2 field spectroradiometer (ASD Co, USA), which allows us to measure the spectral reflectance of soil samples in the range of 350–1050 nm with 1 nm steps. Measurements were made in clear, sunny weather from a distance of 20 cm from the surface of a soil sample. The reflectance of some samples was measured in their wet and dry state.

The sample selection included the most representative soils of the region: chernozemic soils with different humus content, eroded to varying degrees, and carbonate soils. The spectra of surface and subsurface horizons of arable soils were analyzed. Analysis of the spectra of subsurface horizons was used as an additional proxy of the spectra of eroded soil surface.

Data on soil samples’ spectral reflectance were aggregated (calculating weighted average) into the wavelength ranges of the analyzed Landsat TM5 bands. Then, spectral reflectance data for dominant chernozemic nondegraded soil were averaged. The average spectral curve for dominant nondegraded soils of the region in terms of Landsat TM5 bands is shown in Figure 3.

Analysis of the received spectra of soils accounting for specificity of the correlation between spectral reflectance and other properties of soils, described in the literature [27–31], revealed the most general regularities of changes in the reflectance of soils depending on the changes in their humus, carbonate, and moisture contents in qualitative form (higher, lower, and so on). These exact properties of soils in the region of research can potentially influence the change of spectra of the open surface of arable soils. The results were used as the basis for expert analysis of the Landsat reflection difference map.

For example, strong increase of reflectance in Landsat band 1 in combination with increase in other bands indicates increase of carbonatization of soils. Strong decrease of reflectance in Landsat bands 3, and 4 in combination with decrease of reflection in band 2 indicates increasing of moisture content. A strong increase of reflectance in band 3 in combination with an increase in band 4 indicates a loss of humus content in the ploughed soil horizon.

Theoretically, the color of the soil surface can be changed from local events and not from temporal events such as "physical crust" that evolved from the rain drop energy or dust against plowed soil. However, this all depends on the specific of the soils of the region of research. In our case, chernozemic soils are dominant. This means that the difference in spectral reflectance of the soil sample from a ploughed soil horizon and of soil dust from it, as well as of a ploughed soil surface and of physical crust on it, is not very big. Based on Landsat data, and the approach used, only abrupt changes in spectral reflectance can by registered. Further, such changes of soil color in the region of research indicate soil degradation (or rarely soil progradation) processes.

In many cases, soil spectral reflectance affected by iron oxides influence [27]. However, chernozemic soils are rich in humus. It is well known that, if humus content is higher that 5–6% (as in our case), all mineral particles in soil are covered by organic matter, and their input to spectral reflectance in visible and NIR bands is minimal. The iron oxides affect spectral reflection in this region only when soil horizons AB or B are exposed on the soil surface. This is a case of soil erosion. Thus, when we detect an increase of soil erosion, this is due to a reduction of humus content in the ploughed soil horizon, an increasing quantity of iron minerals without organic coating, and their influence on spectral reflection of soil surface.

As a result of expert analysis of the Landsat reflection difference map, all analyzed pixels were reclassified in terms of changes in soil properties.

To assess the accuracy of expert analysis, we used a simple approach. Expert attribution of the observed change in image brightness on satellite data to one or another class of soil property changes was performed by 3 independent experts. In case of disagreement in the assessment results, a joint discussion was held, which resulted in a decision to assign the analyzed change to the class of soil property changes or to their deviation. In the latter case, rejection meant that such a class of changes was not associated with changes in any of the soil surface properties, and it was therefore excluded from further analysis.

Humus loss pixels on arable slopes were attributed to erosion loss class, and on flat surfaces to soil depletion loss class. Separation of the analyzed pixels by slope of the terrain was carried out on the basis of the slope map based on the SRTM digital terrain model [32].

Areas of different change classes were calculated and the data obtained were analyzed. The entire analysis of maps and satellite images was carried out using ILWIS v3.3. ILWIS is an open-source software used for joint analysis of satellite data and other spatial information (digital maps of soil, land use, digital elevation model, administrative boundaries), the functionality of which makes it easy to solve the tasks of this research.

For analysis of the obtained results, the data of the Russian Goskomstat on land use in the Belgorod region were also used [20].

3. Results

The degree of openness of the arable soil surface on the selected scenes of Landsat TM5 allowed for the analysis of about 800 thousand hectares of arable land (about 56% of the total area of arable land in the Belgorod region). On more than 89% of the analyzed territory, the spectra of the soil surface present no change for the period 1985–2010. On the remaining 11% of arable land, some changes in spectra occurred.

For their decoding, soil spectral reflectance curves were analyzed. This allowed us to reveal general regularities of soil reflectance change in Landsat TM5 bands. They are presented as an expert-based graphical model in Figure 4.

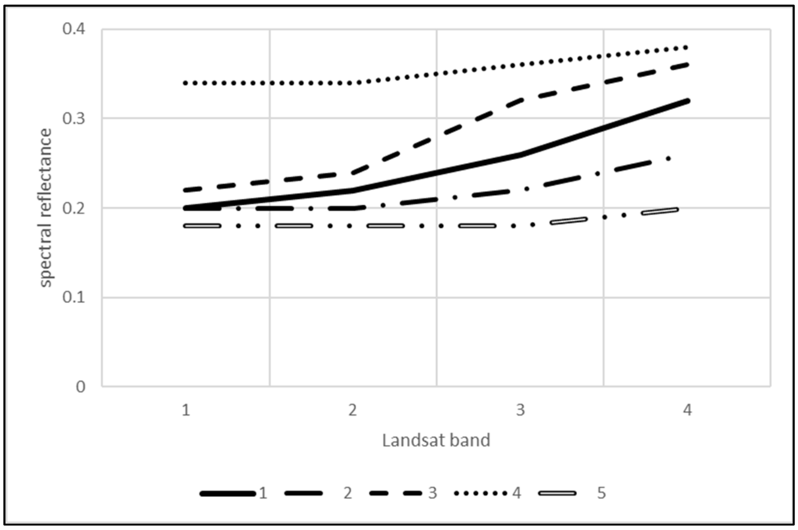

Figure 4. Expert-based model of soil spectral reflectance in Landsat TM5 bands. 1—average spectral curve for dominant nondegraded soils of the region; 2—soil with higher humus content than dominant; 3—soil with lower humus content than dominant; 4—soil with higher carbonates content than dominant; 5—soil with higher moisture than dominant.

The established regularities have been transformed into the form of decisive rules, on the basis of which Landsat difference maps of the open surface of soils were reclassified (Table 1).

Table 1. Decision rules for reclassifying the changes in Landsat reflectance into the changes of soil properties.

Soil Property Changes	**Changes in Spectral Reflectance in Landsat TM5 Bands** [1]			
	1 Band 450–520 nm	**2 Band 520–605 nm**	**3 Band 630–690 nm**	**4 Band 760–900 nm**
no changes	=	=	=	=
humus content increasing	=	-	-	-
humus content declining	+	+	++	+
humidity increasing	-	-	-	–
humidity declining	+	+	+	++
carbonates content increasing	++	++	+	+
carbonates content declining	–	–	-	=

[1] markings for changes in spectral reflectance: = no difference, - weak decline, – strong decline, + weak increase, ++ strong increase.

The result of the reclassification is shown as a map in Figure 5, revealing that the main changes were related to the humus content and the humidity of soils. The increase in the humidity of soils is noted on 37,000 hectares of arable land in the region, the increase of humus content on 29,000 hectares, and the decrease of humus content on 7000 hectares due to plowing of soil and on 6000 hectares due to soil erosion (it is necessary to take into account that not all arable lands of the Belgorod region have been analyzed).

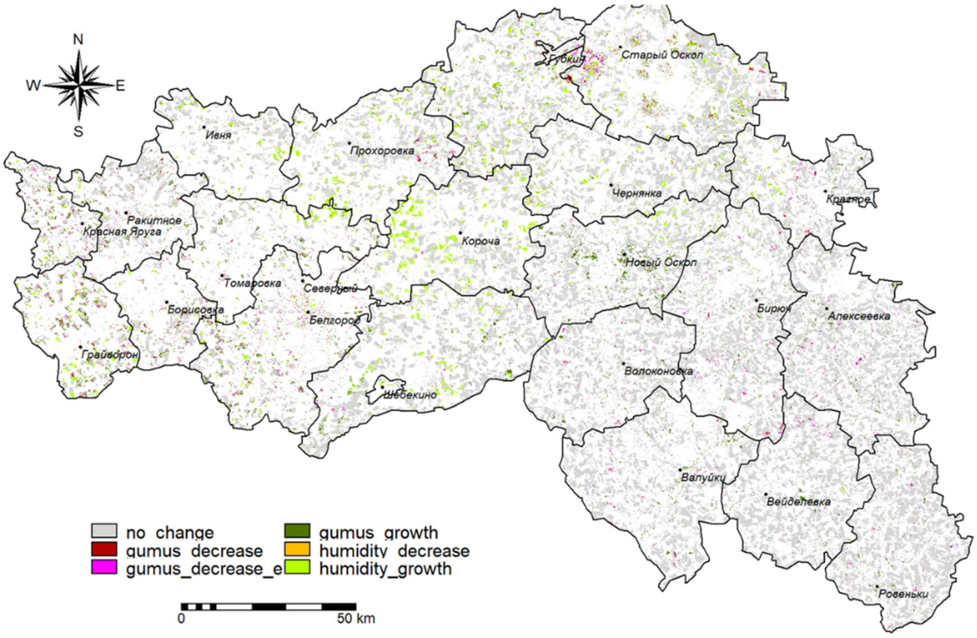

Figure 5. Map of soil property changes of the studied region from 1985 to 2010.

The data on revealed changes by administrative districts of the oblast are presented in Table 2. The least changes were detected in the arable land of Rovensky, Veidelevsky, Valuysky, and Volokonovsky districts. The biggest changes were found in the Grayvoronsky district. The increase in the hydromorphism of soils (soil humidity) is most evident in the data of the Korochansky, Grayvoronsky, and Yakovlevsky districts. The content of humus increased by more than 15% in the analyzed lands in Grayvoronsky, Krasnoyaruzhsky, and Belgorodsky districts. Most of the areas with humus loss were detected for Borisovsky, Belgorodsky, Grayvoronsky, Gubkinsky, and Krasnoyaruzhsky districts, both from plowing and from soil erosion.

The revealed changes in the analyzed soils are given in Table 3. The least changes were observed in ordinary and meadow-chernozemic soils, and the most changes were revealed in alluvial arable soils. The hydromorphism of chernozems increased slightly more compared to other soils. The highest increase in soil humidity was observed for alluvial soils. The percentage of humus content decrease was maximal in alluvial soils, and also in typical and leached chernozems.

Table 2. Identified changes in the properties of arable soils by administrative districts of the Belgorod region between 1985 and 2010.

District	Analyzed Area, ha	Percent from Total Arable Lands Area	Share of Soils with Different Trends in Soil Humidity and Humus Content (in % of the Analyzed Area)					
			No Change	Soil Humidity Growth	Soil Humidity Decrease	Humus Content Growth	Humus Content Decrease	Humus Content Decrease due to Erosion
Alekseevsky	66,251.52	81.91	96.62	0.12	0.00	2.15	0.41	0.69
Belgorodsky	24,841.89	38.4	72.21	6.40	0.03	15.12	2.86	3.38
Borisovsky	10,175.22	30.68	78.24	4.59	0.00	10.50	4.14	2.53
Valuysky	49,486.95	78.42	96.13	0.23	0.00	2.57	0.58	0.49
Veidelevsky	49,337.91	78.35	97.75	0.14	0.00	1.30	0.34	0.47
Volokonovsky	41,280.84	70.73	96.80	0.15	0.00	2.01	0.43	0.61
Grayvoronsky	15,308.19	31.24	53.03	15.31	0.01	22.97	5.57	3.10
Gubkin city	1561.68	77.62	84.28	6.07	0.00	1.56	3.42	4.67
Gubkinsky	46,884.42	66.12	86.52	9.33	0.00	2.87	0.71	0.57
Ivnyansky	17,128.26	32.31	88.74	8.70	0.00	2.31	0.17	0.08
Korochansky	40,116.06	62.23	80.15	18.13	0.00	1.40	0.18	0.13
Krasnensky	26,110.35	71.36	92.52	3.19	0.02	2.66	0.78	0.82
Krasnogvardeysky	56,704.86	82.39	95.79	0.83	0.00	2.03	0.59	0.76
Krasnoyaruzhsky	10,384.2	39.3	71.47	5.88	0.00	15.59	3.42	3.64
Novooskolsky	45,820.89	87.55	89.40	2.75	0.00	7.46	0.20	0.19
Prokhorovsky	35,450.46	47.66	86.84	10.33	0.00	1.53	1.01	0.28
Rakityansky	19,372.77	35.99	86.71	1.66	0.00	7.92	2.16	1.55
Rovensky	58,961.52	82.45	97.89	0.11	0.00	1.10	0.38	0.52
Starooskolsky	55,600.83	93.83	86.05	8.20	0.00	2.35	2.03	1.37
Chernyansky	38,343.78	61.25	93.31	5.85	0.00	0.47	0.17	0.19
Shebekinsky	55,820.34	72.77	89.77	6.58	0.01	3.19	0.24	0.21
Yakovlevsky	14,562.99	24.92	73.32	11.94	0.00	11.76	1.55	1.43
Belgorod oblast	77,9505.9	63.03	89.75	4.80	0.00	3.77	0.89	0.79

Table 3. Identified changes in the properties of arable soils of the studied region by soil type between 1985 and 2010.

Soil Name (Russian Soil Classification Terms)	Analyzed Area, ha	Percent from Total Soil Area in the oblast	Share of Soils with Different Trends in Soil Humidity and Humus Content (in % of the Analyzed Area)					
			No Change	Soil Humidity Growth	Soil Humidity Decrease	Humus Content Growth	Humus Content Decrease	Humus Content Decrease due to Erosion
Grey forest soils	4562.73	0.59	90.29	5.68	0.02	1.88	0.34	1.79
Dark-grey forest soils	50,179.5	6.47	89.13	5.80	0.01	3.60	0.51	0.96
Chermozems podzolized	38,548.71	4.97	85.21	8.05	0.01	3.87	1.81	1.06
Chernozems leached	134,266.41	17.31	91.29	4.12	0.00	3.00	0.80	0.79
Chernozems typical	214,417.53	27.65	88.51	5.37	0.00	4.25	1.18	0.68
Chernozems_ordinary	8858.16	1.14	98.46	0.00	0.00	0.84	0.28	0.41
Chernozems_sodified	35,483.67	4.58	94.35	2.05	0.00	2.15	0.25	1.20
Chernozems residually-carbonated	35,391.33	4.56	87.48	5.77	0.00	5.29	0.37	1.08
Alluvial sods	4809.78	0.62	80.97	12.29	0.00	3.57	2.54	0.62

Table 3. *Cont.*

Soil Name (Russian Soil Classification Terms)	Analyzed Area, ha	Percent from Total Soil Area in the oblast	Share of Soils with Different Trends in Soil Humidity and Humus Content (in % of the Analyzed Area)					
			No Change	Soil Humidity Growth	Soil Humidity Decrease	Humus Content Growth	Humus Content Decrease	Humus Content Decrease due to Erosion
Alluvial meadow-boggy	8656.47	1.12	78.77	9.35	0.00	8.22	2.70	0.95
Chernozemic meadow	9241.29	1.19	84.26	5.94	0.00	6.62	2.93	0.25
Meadow-chernozemic	120.69	0.02	95.30	2.68	0.00	0.67	1.34	0.00
Solonetz	7469.01	0.96	92.66	3.82	0.00	2.80	0.50	0.23
Chernozems typical carbonated	157,027.41	20.25	92.22	3.67	0.00	3.00	0.47	0.64
Alluvial meadow carbonate and gley	28,683.72	3.70	85.86	4.89	0.01	6.89	1.09	1.26
Ravine and gully complexes	19,830.42	2.56	88.93	5.89	0.00	3.72	0.63	0.83
Sod-carbonate washed	3546.18	0.46	89.10	4.87	0.00	3.84	0.14	2.06
Sod soils	10,292.67	1.33	88.87	3.88	0.01	5.44	1.48	0.32
Boggy soils	4058.1	0.52	94.41	0.40	0.00	4.01	1.14	0.04

4. Discussion

Utilizing the proposed approach, only 56% of the arable lands of the region were analyzed. It was not possible to analyze all arable lands due to the high share of winter crops and perennial grasses cultivated in the region. Theoretically, the analyzed area can be increased by including the Landsat images of other years in the analysis (for example, 1986 and 2010, in our case). Due to the crop rotation, plots with winter crops in 1985 should have an open soil surface in spring of 1986, and in 2010 other plots will have a more open soil surface compared to 2011. Nevertheless, it is practically impossible to consider all arable lands in the analysis.

The obtained models of changes in soil spectral reflectance depending on changes in individual soil properties do not contradict those established by other authors earlier [27–31]. In general, the regularities found for chernozem soils in the Belgorod region confirm them. We found it possible to reliably identify soils that have lost humus, which is associated with the peculiarities of soil profile composition in the region and the change of their color with depth. The darkest horizons with low reflectance are gradually transformed with depth into lighter horizons of a different coloration. Therefore, the process of soil erosion—when humus horizon is washed off—is identified reliably enough by the change in the color of a soil surface. In the case of plowed-out soils, the decrease of humus content in the surface layer also leads to its lightening. These processes cannot be identified if the humus content in the surface soil layer remains above 6% [33]. However, in the arable soils of the region, it is lower than 6% in most cases, which indicates rather reliable detectability of such changes.

An increase in humus content can only be detected based on the applied approach until it reaches 6%. Further growth has no effect on changing the reflectance of soils in visible and NIR Landsat bands.

The content of carbonates in the surface horizon of arable soils of the region is small. They are present in large quantities only in residual carbonate chernozems, the share of which in arable lands is low. As a result of our analysis, changes in the carbonate content of soils on very small areas have been revealed in the southeast of the region, which is most likely due to the erosion processes on soils of slopes with close sub-bedding of chalk rocks.

The influence of soil moisture on its spectral reflectance is also well studied [29,34]. The main regularities revealed earlier were confirmed by our experiments. However, in real field conditions, when moisture is not pulled up to the soil surface, the surface of wet soil dries up quickly enough. After rainfall, the surface of arable soil becomes dry in sunny weather after 2–3 h [34]. Considering that satellite images from a clear sunny day are used in the analysis, the open surface of arable soils should be dry, despite the high probability of sufficient moisture content in the arable horizon itself. Thus, the moisture content of the arable horizon should not affect the reflectance of the soil surface detected by the satellite sensor on a sunny, cloudless day. The influence of moisture can be present only in the case of its constant capillary rise to the surface, the speed of which prevents the evaporation front from penetrating deep into the arable horizon. Such cases occur when the groundwater or intrasoil water horizon is close enough. Most of the region's soils are characterized by quite deep groundwater occurrence, but intrasoil water is present quite often. Its occurrence is usually associated with both increased precipitation and the presence of a texture change in the soil profile, or the presence in the soil profile of a resealed plowed horizon (so called, "plow sole") [35,36]. In this case, the soil surface can remain wet even on a sunny, cloudless day. Such changes have been shown on the map (Figure 4) under the term "increased humidity (hydromorphism) of soils".

Judging by the map in Figure 4, the revealed changes show no clear geographical pattern for the territory of the oblast. However, pixels with increased hydromorphism of soils are slightly more concentrated in the western part of the region and pixels with humus loss due to erosion in the eastern part of the region. Most changes are found in nearly all districts of the studied region, indicating that observed changes are more related to specific land use than to the spatial trends of climatic or soil conditions. On the neighboring arable plots, different changes can be observed. The analysis of areas with changes within the administrative districts of the region or for individual soils revealed similar regularities.

The main factors leading to the identified changes are most likely to be the observed climate change and the specifics of agricultural land use in the region.

The wide introduction of adaptive landscape farming systems in the Belgorod region at the beginning of the current century and the expansion of forage crops, as well as perennial and annual grasses, could lead to improved balance in the input and output system of organic content in arable soils [12], in turn leading to the observed increase in humus content in arable horizons of soils in individual areas and plots.

As mentioned above, the decrease in humus content in arable soil horizon can be connected with plowing of soils, especially on old arable lands, and also with water erosion processes affecting soils on the slopes. These processes are still quite widespread in arable lands in the chernozemic zone [37]. An additional trend is the increase in precipitation in recent years, especially in the form of heavy rains [38].

The development of secondary (including surface) hydromorphism processes in recent years has been a significant problem for the entire Russian chernozemic zone. The following reasons are usually mentioned as the main ones: (1) the irrigation leading to a rise in the groundwater level; (2) the regulation of the runoff of steppe rivers and reduction of their drainage capacity; (3) the blockage of inland and surface runoff by roads and forest belts; (4) the compaction of soils by heavy machinery; (5) the increase in precipitation [39].

For the Belgorod region, the leading causes of the secondary hydromorphism seem to be soil compaction and increased precipitation. On flat surfaces of the watersheds, there may also be spring stagnation of the melted snow water and atmospheric precipitation accumulation in the microdepressions, which leads to surface waterlogging of arable chernozems, similarly to the neighboring chernozemic regions [40]. On the slopes of the eastern and southeastern parts of the region, periodic overwetting may also be associated with the areas of so-called "mochary", which often also spread to the arable land [41,42].

It should be noted that the revealed changes do not indicate that the position of soils in the soil classification is changing. Only cases of humus loss on slopes can indicate that soils from the class of "weakly eroded" soils have moved to the classes of "medium and/or strongly eroded". All other cases indicate only a change in the individual properties of the arable horizon of soils.

Furthermore, the obtained results should not be taken as comprehensive information on changes in soil properties over the period under analysis. On the basis of this approach, it is possible to identify the trend only for those properties of soils that affect the change in color of their surface, though there are many other changes in soil properties that cannot be identified by this method.

In chernozemic soils, the analyzed properties are often used as a main indicator of their degradation status and soil health.

It should be considered that not all arable soils of the region have been analyzed, only part of them. However, it can undoubtedly be considered as a representative sample set to assess the trend of the analyzed properties of arable soils of the Belgorod region.

5. Conclusions

The analysis of Landsat TM5 images showed that the color of the open surface of arable soils of the Belgorod region changed little in the period from 1985 to 2010. Only on 11% of the investigated territory were color changes observed. Most of them are associated with the changes in humus content in soils or their moisture.

The observed changes are most likely due to the specific changes in the use of arable land in the region, as well as observed (intracentury) climate changes. The reaction of soils to the joint impact of these factors is different depending on their properties, which creates a rather chaotic picture of the geography of observed changes.

The expert model of the linkage between soil spectral reflectance changes and their property changes is regional and cannot be transferred to other regions with different soils. However, this approach can be applied in any region after building regional models of spectral reflectance of arable soil changes as a result of changes in their properties.

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