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TRENDS IN SOIL CHANGES IN THE SOUTH-WEST OF THE BELGOROD REGION

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The analysis of the Landsat 5 satellite data helped to study the processes of soil changes which took place from 1991 to 2011 inclusively at the test site located in the south-west of the Belgorod Region. As a result, it was found that despite intensive agricultural land use the proportion of soils, the properties of which have changed over the past 20 years, within the total area studied is quite small. The changes of soil erosion status were recorded within the territory of no more than 1 % of the total area; the territories characterized by soil humus losses on subhorizontal surfaces cover no more than 2 % of considered area. The most intensive process among the others is humus accumulation in the soil, the increase in humus content is noted on 5.6 % of the analyzed area. The identified tendencies in soil changes may be due to both the specifics of agricultural land use and climate changes.

Keywords: soil monitoring, soil erosion, soil spectral reflectance, Landsat 5.

INTRODUCTION

Belgorod Region has rich soil resources characterized by high fertility. Chernozems, widespread in the region, which share in the territory is more than 70 % of soil cover, are suitable for agronomical cultivation of cereals, technical and many other crops. The areas under cultivation in Belgorod region occupy up to 1 449.3 thousand ha that is 1.8 % of total sown area in Russia. According to "bel.ru" news agency, in 2014 Belgorod region became the first in the Central Federal District on grain yields and the second on this indicator in Russian (http://bel.ru).

Soil erosion along with soil humus loss refers to a most common type of soil degradation in the region. These phenomena cause irreparable environmental damage and lead to negative economic consequences, threatening the very existence of the soil as a main component of agricultural production. It is necessary to take into account that the area of Belgorod region is the most eroded among all the regions of the CCD (the Central Chernozem District). According to 2011 data, the eroded soil area was 53.6 % of the entire region (Uvarov, 2010).

Apart from erosion in Belgorod we can see other soil degradation processes in a large scale: soil humus loss, agro exhaustion, acidification. The total area of degraded arable soils in the area is 952 468 hectares (Lukin, 2016). Due to a combination of factors, which include topography, climate, nature of soil-forming materials and uneven anthropogenic impact, the phenomenon of soil erosion is widespread in Belgorod region. Shower-like precipitation in the territory, plowing of forage lands, anti-erosion measures ignoring cause water erosion in the region. However, these manifestations are not widespread.

Thus, the assessment of soil cover and soil erosion processes in the area is an extremely urgent task at the moment since most of the lands are ones for agricultural needs, and economic prosperity of the region depends on the fertility and the soil resources. Moreover, recent years have seen more intensive agricultural production in the region which also indicates that the assessment of ecological consequences of this activity type is topical.

The traditional approach to estimating the degree of soil degradation is based on the integral principle, including the soil analysis on agrophysical indicators, the risk of erosion, physico-chemical, biochemical and hydro-geochemical indicators (Kovalev, 2015). Classical methods for diagnosis of soil erosion processes use the indicators of area compartmentalization, humus reduction and capacity of soil profile, flushing rate (Voznesenskii, 1936; Larionov, Litvin, 1984; Egorov, 2009). However, in recent years the advance in mapping technologies and related sciences call for necessity to create some new methods to solve the problems related to monitoring of soil erosion processes and quantity assess of soil degradation in large territories, based on deciphering satellite data or data obtained from the UAV. (Siakeu, Oguchi, 2000; Vrieling, 2006; Gafurov, 2017; Kashtanov et al., 2018). The use of long-term archive Landsat satellite data helps to evaluate spatial and temporal changes of soil processes based on the change of color characteristics of soil surface (Savin et al., 2016).

The article provides the results of satellite data use in assessing long-term changes in soil cover at a test plot in Belgorod region.

MATERIALS AND METHODS

The object of the study was the test plot on the FSUE "Belgorodskoye" land in Severny township of Belgorod Region, 10 km north from Belgorod (Fig. 1).

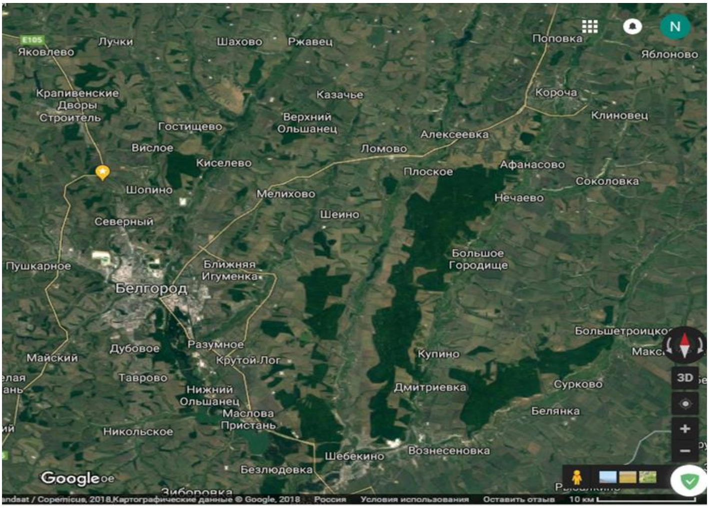


Fig. 1. Polygon area on Google Maps map (yellow label).

The topography which was formed on the most territory is complicated by river valleys and beams, that is morphs-structural type of erosion-denudation plain.

The climate of the study area is a continental mild one with relatively mild winter, with snowfalls, thaws and hot summer with often drought and dry winds. The average annual precipitation amounts to 400–600 mm (varying from 260 to 750 mm in some years). Up to 85 % of the precipitation is in the form of rain and the rest are solid, predominantly in the form of snow. The most common type of soil-forming materials in the region are loess loams formed in the epoch of maximum stage of Valdai glaciation (Chendev, Petin, 2006).

Three sections were used for the base soil characteristic: flat watershed, the middle part of southern exposure slope (1°–3°) and its lower part (3°–5°) embodied and described by A.M. Grebennikov and V.A. Isaev in 2017 (Fig. 2). Soil sections were laid on elementary landscapes of different subordination levels to identify the grade of erosion process manifestation in the investigated range.

Fig. 2. Soil-erosion catena on the test plot.

It was assumed that the most significant development of erosive processes was expressed at the bottom of the slope with a curve up to 5°, whereas on the autonomous landscape flat watershed they are minimally expressed.

The coordinates of section laying – on the watershed:

(50°43'03" N; 36°31'51" E), in the middle (50°42'49" N; 36°31'41" E) and in the bottom (50°42'42" N; 36°31'36" E) parts of the slope.

The soils of three sections were identified as the migration-micellar agro-chernozems of little humus content loams (Shishov et al., 2004). The soils of sloping position (sectional №№ 2 and 3) are hydro-metamorphosed ones. In accordance with the classification (see above) all the soils belong to the chernozems of little humus content. In general, there is a regular pattern of humus content reducing in all three soil sections, and its contents throughout the soil profile reaches its maximum in the section № 1 (in horizon PU 5.2 %) and its minimum in section № 3 (a horizon PU 4.3 %).

The soils of the section number 1 on the humus horizon capacity could be related to ones with high capacity, of 2nd and 3rd sections – to chernozems with average capacity. However, their capacity reduction, most likely is linked to the erosion of this slope-type soils.

Down the hill there was a series of changes in the soil morphological properties (Fig. 3.): increased capacity of the plow horizon and decreased capacity of AU, Aub,ca horizons. Also, there was an increase in free-carbonate depth and growth in hydro-metamorphism characteristics with increasing subordination of soil section position.

In the studied soils one can find carbonate veins in accumulative-carbonate horizon. In general, carbonate distribution in the soil profile is quite usual for typical chernozems, carbonate maximum is well defined and confined to the horizon Bca. We should note a shortened carbonate profile at the bottom of the slope due to the decrease in capacity of soil-forming loess loam.

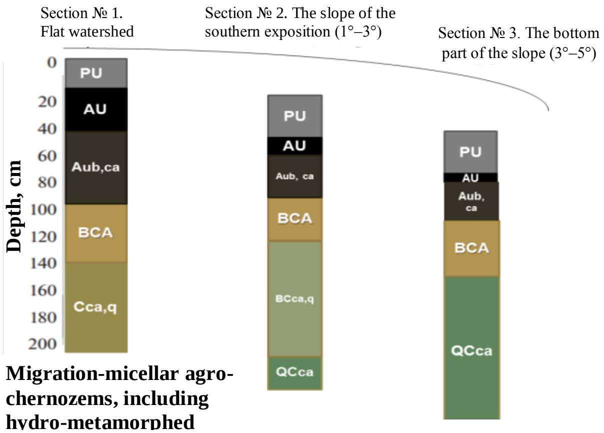


Fig. 3. Soil-erosion catena and soil profiles of laid sections.

According to their morphological properties the soils of sections 2 and 3 were diagnosed as weakly washed-out (Classification..., 1977). Thus, the structure of the plot soil cover is represented by chernozem erosion combinations involving meadow chernozem soil, slope gullies and hollows. The part of eroded soils in combination amounts to about 40 % and the percentage of meadow chernozem soil usually does not exceed 10 %. Thus slightly eroded soils predominate among eroded ones, moderately eroded soils are presented to less extent in the edge part of arable massif.

Satellite images Landsat TM5 (https://landsat.usgs.gov/landsat-5-history) were used to study the spatial and temporal changes in soil. Two geometrically linked cloudless scenes of different years (1991 and 2011) of shooting were selected from the archives of satellite data obtained under similar conditions in autumn, considering the circumstance that deciphering the images of summer period the vegetation is an obstacle to soil cover monitoring while in the winter time it is a snow cover.

Image processing was performed using ILWIS software package (Savin, 2015). The final map design was also performed using ArcGIS (http://www.arcgis.com). The shooting channels Landsat TM5 1-2-3-4 were selected for analysis in the visible and infrared spectrum.

Each image was classified into three groups: open soil surface, water objects and vegetation. For this purpose, the vegetation index NDVI (http://gis-lab.info/qa/ndvi.html) was calculated for pictures of two years (1991 and 2011). The classification was built by expert selection of the NDVI boundary values for each of the above classes, since it is known that the values of this index are the lowest for open water surface, the higher values characterize open soil surface and even the higher values – vegetation.

The next step was to create a mask of open soil surface for the images for two years under study. Subsequently, two images of different times were intersected with each other, where exclusively the parts with the soil surface deprived of vegetation on both shooting dates were analyzed. Threshold values for the class "open soil surface" were selected individually for each scene and "with allowance" in order to exclude doubtful pixels.

A further stage of the work was normalization of the image tone of open soil surface in each of the survey channels, i.e. the difference in the image tone of later and earlier shooting date was calculated. A histogram of different values distribution was studied for each difference. The basis formed the principle that the difference close to 0 (the absence of tone changes) is prevalent. In case of large deviations of the tone modal values (more than 10 values from 0), the tone was corrected and brought to 0. Subsequently, comparing the tone values and their changes in each channel in dynamics, we traced the difference in the tone of soil image between the scenes of 1991 and 2011, and interpreted it in terms of changes in soil properties. Images of later and earlier shooting data were subtracted channel by channel in order to assess changes in the image tone. Changes in tone for each channel were divided into classes:

- the tone is slightly reduced – from −25 to −10;
- no changes – from −10 to +10;
- slightly increased – from +10 to +25;
- greatly increased – more than +25.

The maps of the classes of tone change differences are then successively intersected with each other. The resulting list of all changes combinations for each pixel was expertly interpreted. The interpretation was based on the model of image tone changing for the plot "Plavsk" with the predominance of chernozems from the article (Savin et al., 2016). The model was tested according to the data obtained from analysis of spectral reflectivity of soil section samples mentioned above. The spectral reflectivity of the soil samples was carried out using a HandHeld2 field spectra-radiometer (http://www.asdi.com/products/fieldspec-spectroradiometers/handheld-2-portable-spectroradiometer). The final version of this model is presented in Table 2.

Based on the use of the above model and the map of terrain slopes, constructed according to the SRTM data (http://srtm.csi.cgiar.org), a map of changes in the properties of the soil surface at the test site was created. It was assumed that the decrease in humus content on the slopes is due to soil erosion, while on the flat surface it is caused by soil humus loss.

Table 2. Model of changes in tone of open soil surface image

Soil Property	Landsat 5 TM Channels			
	Channel 1	Channel 2	Channel 3	Channel 4
No changes	=	=	=	=
Erosion growth	=	=	++	+
Humus reduction	+	+	+	+
Humus growth	–	–	–	–
Increase in hydromorphism	–	–	– –	– –
Decrease in hydromorphism	+	+	+	++

Note. The signs for changes in tone: "="– there is no difference, "–"– slightly decreased, "– –" – greatly decreased, "+"– slightly increased, "++"– greatly increased.

RESULTS AND DISCUSSION

Figure 4 shows a map of identified changes in the area of the research site. The results are shown in Figure 5 in the form of a diagram. From the data obtained on the basis of the created map analysis (Fig. 4), it follows that in general soils with surface color that virtually did not change for the study time predominate, which indicates the absence of soil degradation processes. The share of analyzed pixels that belong to this class exceeds 90 %. Analyzing the diagram shown in Figure 5 we can conclude that among all the soil changes during the study period the increase in humus content leads, which is noted in 5.6 % of the analyzed territory. Presumably, the occurrence of such a phenomenon should be associated with an increased application of organic fertilizers in the farms of the region, which also causes an increase in soil humus content, and with higher agricultural biologization in the region as a whole.

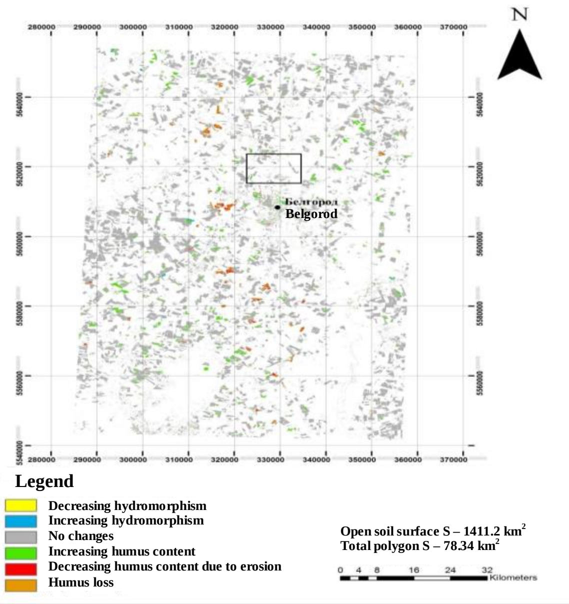
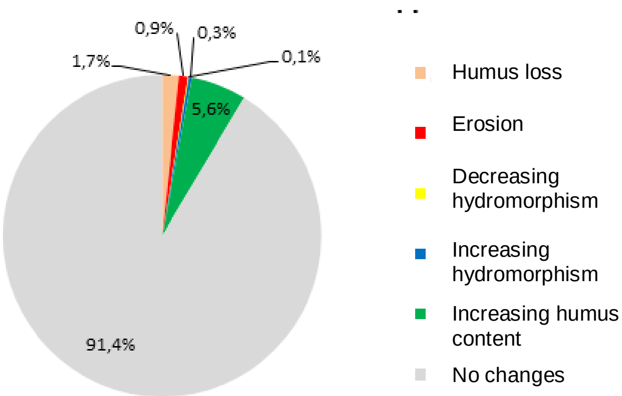


Fig. 4. Changes in soil surface properties in the area of the study plot from 1991 to 2011.



Open soil surface S – 1411.2 km^2
Total polygon S – 78.34 km^2

Fig. 5. Diagram of the factors which cause changes in soil properties in researched area from 1991 to 2011.

Since 2006 due to intensive development of the livestock sector in Belgorod Region the use of organic fertilizers in the region has significantly increased. (Chekmarev et al., 2011). In 2005 the volume of organic fertilizers in Belgorod Region was 0.9 t/ha, then in 2011 they increased to 3.0 t/ha (Short Stat. Collection: Belgorodstat, 2016). However, such an increase in organic fertilizers application was not widespread. For example, according to S.V. Lukin's data (Lukin, 2011), the introduction of organic fertilizers in the period of 2005-2009 on average was close to 0.2–0.3 t/ha in Krasnensky and Alekseevsky Districts, while in Ivnyansky, Krasnoyaruzhsky, Yakovlevsky Districts (where our test polygon is located), more than 2 t/ha were introduced. All this, apparently, led to the divergence of the changes processes in humus content (from its growth to fall) in the research area.

So, 1.7 % of the analyzed pixels show soil humus loss of arable soils. This process in arable layer is most likely associated with a decrease in organic matter supply and mineralization of easily degradable compounds during soil plowing (Mukha, 2004). According to V.D. Mukha, a decrease in "total humus" content under agricultural soil use occurs mainly due to detritus loss. Among the reasons for decrease in humus content on plowed soils one should notice a local reduction in organic fertilizers application and organic matter consumption for crop formation, which was widespread in the area in the 90s of the last century.

A decrease in humus content due to erosion process is ranked as a third factor of changes in the soil cover revealed for the 20-year study. This phenomenon is mainly found on sloping plowed surfaces with the degree of slope more than 3°–5° and is generally recorded for 0.9 % of the analyzed pixels in the study area. This can serve as an indirect indicator of changes in the areas of average and highly eroded soils. That is, the share of such soils from 1991 to 2011 remained virtually unchanged and increased by no more than 1 % in total soil cover of the territory.

No more than 0.4 % of the plot territory is subject to the change in the degree of soil hydromorphism, where the biggest part (0.3 % of the analyzed pixels) is dominated by increase in hydromorphism. In recent years, chernozems of forest-steppe and steppe zones are characterized by the appearance of secondary hydromorphism and the compaction caused by surface and ground waterlogging (Chendev, Petin, 2006). Based on comparison of the obtained map (Fig. 3) and the SRTM terrain model it can be concluded that the increase in the proportion of hydromorphic and semi-hydromorphic soils is confined mainly to negative topography forms both on watersheds and on meso-slopes.

It should be noted that the percentages shown above of the prevalence of any type changes are calculated not for the entire territory rather than for the surface of arable soils, which was open for direct analysis by satellite data during the considered shooting periods. However, taking into account the fairly uniform distribution around the plot areas with an open surface (Fig. 3), we can consider these field samples quite representative for the research region.

In addition, the approach used in this work is applicable exclusively for the diagnosis and monitoring of the soil properties that affect color characteristics of their surface. Moreover, we studied the changes only for two observation periods, which, of course, is not sufficient to identify the exact trends in the dynamics of soil-erosion processes.

CONCLUSIONS

As a result of the studies it was found that despite the high degree of economic use the proportion of soils, which properties have changed over the past 20 years, is small in the total research site area: soil erosion status has hardly changed only in the area which does not exceed 1% of the total site, and soil humus loss on sub-horizontal surfaces can be noted in no more than 2 % of the research area. Among the processes the increase in humus content in soils is ranked number one, which is noted in 5.6 % of the studied territory. The revealed direction of soil changes may be due to the specifics of agricultural land use.

The obtained results can serve as a basis for detailed and updated information on the state and properties of the soil cover in the territory, as well as the further study and monitoring of soil-erosion processes based on the use of spectra-zonal satellite image data.

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REFERENCES

1. *Belgorodskaya oblast v tsifrakh*: Krat. stat. sb (Belgorod region in figures: Breif Stat. Issue), Belgorodstat, 2016, 289 p.

2. Gafurov A.M., Vozmozhnosti ispol'zovaniya bespilotnogo letatel'nogo apparata dlya otsenki pochvennoy i ovrazhnoy erozii. (Possibilities of using an unmanned aerial vehicle for assessing soil and gully erosion), *Uchen. zap. Kazan. un-ta. Ser. Estestv. nauki*, 2017, Vol. 159, book 4, pp. 654–667.

3. Voznesenskii A.S, Artsruni A.B., Fiziko-khimicheskiye svoystva pochv kak faktor poverkhnostnogo smyva (Physicochemical properties of soils as a factor of surface flushing), *Bul. Zakavkazskogo NII Vodnogo khozyaystva*, 1936, No. 12–13, pp. 225–253.

4. Egorov I.E., Polevyye metody izucheniya pochvennoy erozii. (Field methods of studying soil erosion), *Vestn. Udm. un-ta. Ser. Biologiya. Nauki o Zemle*, 2009, Issue 1, pp. 157–170.

5. Karmanov I.I., *Spektralnaya otrazhatelnyaya sposobnost' i tsvet pochv kak pokazateli ih svoistv* (Spectral reflectance characteristics and color of soils as indicators of their properties), Moscow: Kolos, 1974, 351 p.
6. Kashtanov A.N., Verniuk Yu.I., Savin I.Yu., Shchepotiev V.N., Dokukin P.A., Sharychev D.V., Li K.A., Kartografirovanie rucheikovoy erosii pakhotnyh pochv po dannym s bespilotnykh letatelnykh apparatov (Mapping of rill erosion of arable soils based on unmanned aerial vehicles survey), *Pochvovedenie*, 2018, No. 4, pp. 506–512.
7. *Klassifikatsiya i diagnostika pochv SSSR* (Classification and diagnostics of soils in the USSR), comp. by V.V. Egorov, V.M. Friedland, E.N. Ivanova, N.N. Rozov, V.A. Nosin, T.A. Friev, Moscow: Kolos, 1977. 220 p.
8. Kovalev N.G., *Metody otsenki stepeni degradatsii sel'skokhozyaystvennykh zemel'* (Methods for assessing the degree of degradation of agricultural lands), Kolomna: Raduga, 2015, 32 p.
9. Larionov G.A, Litvin L.F, Zaslavsky M.N., Faktory erozii (Erosion factors), In: *Erozionnyye protsessy* (Erosion processes), Moscow, 1984, pp. 48–57.
10. Lukin S.V., *Agroekologicheskoye sostoyaniye i produktivnost' pochv Belgorodskoy oblasti* (Agroecological condition and productivity of soils of the Belgorod region), Belgorod: KONSTANTA, 2011, 344 p.
11. Mukha V.D., *Yestestvenno-antropogennaya evolyutsiya pochv (obshchiye zakonomernosti i zonal'nyye osobennosti)* (Natural and anthropogenic evolution of soils (general regularities and zonal features)), Moscow: Kolos, 2004, 271 p.
12. Orlov D.S., *Spektralnaya otrazhatelnaya spsonost' pochv i ih kompontentov* (Spectral reflectance characteristics of soils and their components), Moscow State University, 2001, 175 p.
13. Savin I.Yu., *Deshifrirovaniye pochvennogo pokrova lesostepi Tsentral'no-Chernozemnogo rayona po srednemasshtabnym kosmicheskim snimkam: Avtoref. Diss. kand. geogr. nauk* (Detection of soil patterns of the forest-steppe of the Central Black Earth region based on medium-scale satellite imagery, Cand. geogr. sci. thesis), Moscow, 1990. 30 p.
14. Savin I.Yu., *Aerokosmicheskiye metody v sel'skom i lesnom khozyaystve (komp'yuternyy praktikum)* (Aerospace methods in agriculture and forestry (computer workshop)), Moscow: RUDN, 2015, 112 p.
15. Savin I.Yu., Isaev V.A., Shishkonakova Ye. A., Zhogolev A.V., Veretelnikova I.V, Turchinskaya S.V., Trendy degradatsii pakhotnih pochv Rossii, viyavlennye po sputnikovym dannym Landsat (Trends of degradation of arable soil in Russia, identified by satellite data Landsat), *Vestnik Rossiyskoy selskokhozyaystvennoy nauki*, 2016, No. 4, pp. 53–55.

16. Uvarov G.I., *Degradatsiya i okhrana pochv Belgorodskoy oblasti (*Soil degradation and protection in the Belgorod Region), Belgorod: “Otchiy kray”, 2010, 180 p.
17. Chekmarev P.A., Rodionov V.Ya., Lukin S.V., Opyt ispol'zovaniya organicheskikh udobreniy v Belgorodskoy oblasti (Experience in the use of organic fertilizers in the Belgorod region), *Dostizheniya nauki i tekhniki APK*, 2011, No. 2, pp. 3–5.
18. Chendev Y.G., Petin A.N., *Yestestvennaya izmenchivost' i antropogennaya transformatsiya komponentov okruzhayushchey sredy ekspluatiruyemykh regionov (na primere Belgorodskoy oblasti)* (Natural variability and anthropogenic transformation of the environment components of exploited regions (on the example of the Belgorod region)), Moscow: MSU Publishing house, 2006, 124 p.
19. Shishov L.L., Tonkonogov V.D., Lebedeva I.I., Gerasimova M.I., *Klassifikatsiya i diagnostika pochv Rossii* (Soils Classification and Diagnostics of Russia), Smolensk: Oikumena, 2004, 341 p.
20. Siakeu J., Oguchi T., Soil erosion analysis and modelling: a review, *Trans. Jpn. Geomorphol*., 2000, Vol. 21, No. 4, pp. 413–429.
21. Vrieling A., Satellite remote sensing for water erosion assessment: a review, *Catena*, 2006, No. 65, pp. 2–18.