

Conference Paper

Soil-Agroecological Types of Lands of the Petrovsky District in the Tambov Region of Russia

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¹Moscow State University, GSP-1, Leninskie Gory, Moscow, Russia²Dokuchaev Soil Science Institute, Moscow, Russia**ORCID:**Anna Murman: <http://orcid.org/0000-0002-0998-649X>**Abstract**

This article describes methodological approaches and results for digital mapping of water-migrational and erosional-accumulative soil cover structures for the forest-steppe of Tambov Plain. Such maps form the basis for applied maps such as for agroecological studies, forestry, landscape planning, etc. In this study, soil-landscape relationships were simulated as one of the subsystems of structure-functional organization. Linear discriminant analysis, random forest and the supported vector machine were used as simulation methods. The training sample consisted of 256 soil points. The Digital Elevation Model (DEM) had a spatial resolution of 25×25 meters. The simulation was provided for interfluves and valleys separately. A number of factors that describe soil cover type formation within interfluves and valleys were determined. It was established that within interfluves, determinant covariates are linked with moisture regime, whereas factors of lateral transfer and accumulation are most significant within valleys. The hierarchical nature of structure-functional organization was determined. The comparison of the results of the three simulation methods showed that the supported vector machine had the best accuracy values. However, verification by soil maps had the best correlations with the results of the linear discriminant analysis. In addition, soil-agroecological types of lands and their detailed descriptions for the key area were proposed on the basis of the simulation results of the soil combinations.

Keywords: soil-agroecological types, soil cover structures, landscape-adaptive agriculture, digital soil mapping

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1. Introduction

Since the beginning of the XX century Russian scientists [1, 2] accounted for agricultural dependence on geomorphological, hydrological and other natural factors and about the landscape approach. Those ideas were advanced by V. Fridland [3] through his soil cover types theory. Afterwards A. McBratney created SCORPAN model [4], where S – soil properties, C – climate, O – organisms, R – relief, P – parent rock, A – age and N – spatial position. The model describes relationships between soils and

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soil formation factors. Soil cover is one of the landscape significant components. Via properties of soil cover it is possible to predict the land type (landscape) and its features. On the other hand, landscape is considered as a system that consists of elementary components (structure) and is connected via processes (functioning). The structure-functional organization (SFO) is implied as a complex of elementary soil and landscape formation processes connected with a morphological structure. Let us compare to other subsystems that can describe the SFO, soil-landscape relationships become one of the most widely used, well-developed and accessible in the conditions of agroecosystems [5].

An evolution of modern computer and digital technologies in relation to spatial analysis form appropriate options for soil-landscape relationships determination as the subsystem of the structure-functional organization and the base for soil cover mapping [6]. However, soil-forming factors are not always coincide with soil cover structures due to high heterogeneity and complexity of soils. Also, uncertainty is related to limits of simulation methods, the scale of modeling and errors in training data. The heterogeneity of the soil cover due to natural factors leads to frequent discrepancy between the observed soils and soil formation factors. Therefore, the analysis of the system through the concept of “factor-process-property” by I.P. Gerasimov [7] is important in establishing soil patterns.

The aim of the study is to discover the structure-functional organization of landscape properties, to find the best relationship of spatial variability of the soil classes with soil-forming factors. Moreover, the usage of three different methods allow comparing results and estimating the quality of the models.

2. Methods and Equipment

2.1. The study area

The key area is located in the east of the Tambov region within the Oka-Don province of lowland moraine-eroded plains (Figure 1). The study area is an alluvial-outwash plain with valleys, series of paleocryogenic depressions and a complex of above-floodplain terraces. Interfluves are composed of the Pliocene sands covered with clay. These rocks are overlaid with Quaternary loam of 1-3 m in thickness. The study area is characterized by slow drainage due to gentle slopes of the surface, the presence of an impermeable loams and clay, a shallow groundwater level (3 - 6 m). The steepness on more than 87% of the area does not exceed 1.2 °.

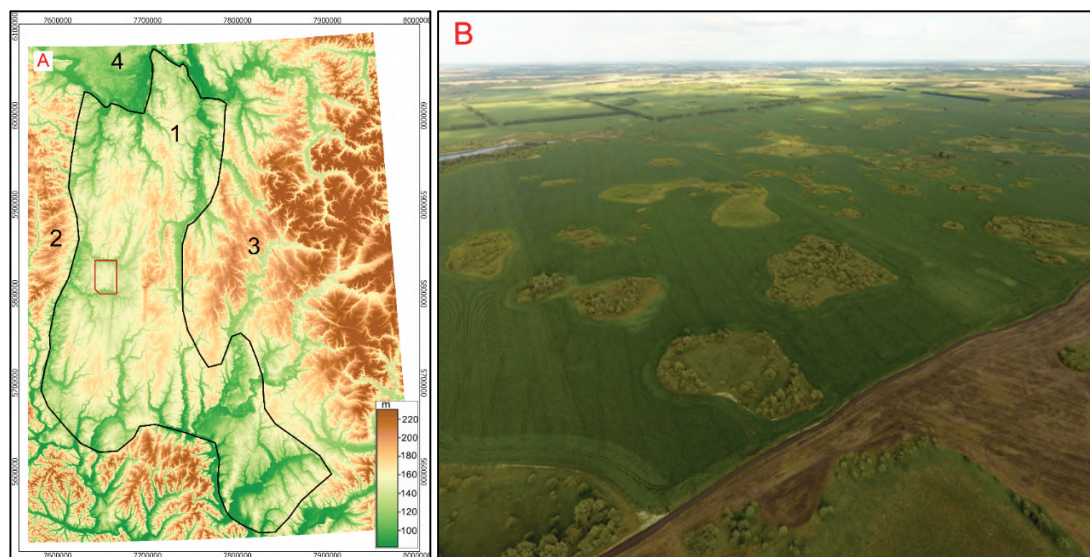


Figure 1: A) The location of the key site on the Oka-Don lowland (1). Other designations: 2 – Central Russian Upland, 3 – Volga Upland, 4 – Meshera lowland. B) The typical landscape of non-drained plains

The main soil type is meadow-chnozems (MCh) with the groundwater level of 3-6 m depth. In sinks where the groundwater level varies from 1 to 3 m, gleyed (MChg) meadow-chnozems are formed. Deep sinks are indicated by boggy (Pb, Mb) grey forest gleyic (Gfg) soils and groundwater level of 1-2 m. If the groundwater level is deeper than 6 m, chnozems (Cht, Chl) and light-grey forest (Lgf) without any signs of waterlogging are formed.

The detailed study of soil cover of the region makes it possible to create the model of soil-landscape relationships. Soil cover differentiation is estimated via DEM of 25×25 m resolution created on the base of topographic maps with contour intervals of 2.5 m. Such spatial resolution is suitable for meso- and micro topography description that explains soil patterns formation depending on DEM-derived factors [3, 8, 9]. In the SAGA program [10] 30 derivative attributes were calculated. Moreover, the SIMulation Water Erosion model (SIMWE) was run in the GRASS program [11, 12]. Results show places with the extra amount of water that remained after infiltration and surface runoff redistribution (Figure 2).

Soil combinations were selected as indicators of the land structure as the only available component for a full study under conditions of widespread plowing. The set of 256 soil sampling points was divided into 2 groups – soils of interfluves (Ch, Mch, Mchg, soils of sinks) and soils of valleys (Lgf, alluvial, eroded, soils of erosion systems) according to the topography segmentation module [10]. Moreover, some soil categories were combined into larger groups according to soil similarity (Table 1) with a view to increase representativeness of training sample and make it more statistically

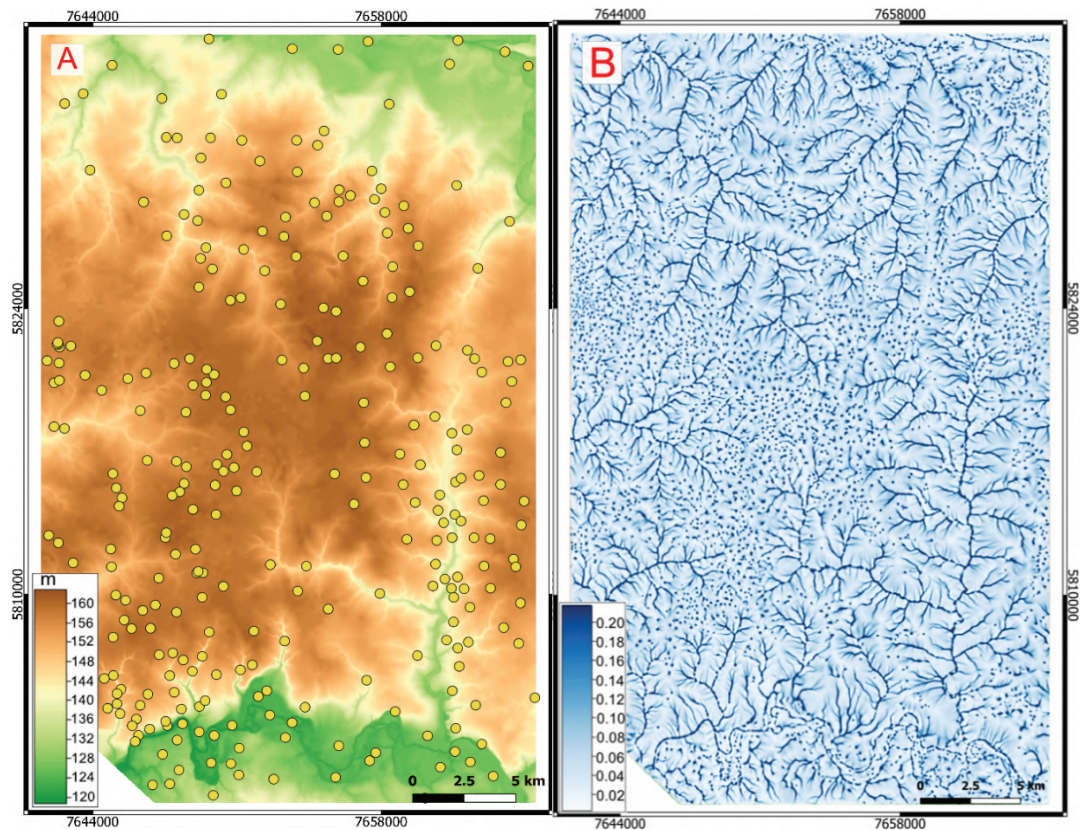


Figure 2: A) Digital elevation model (DEM) of the key area and location of soil sampling points. B) SIMULATION Water Erosion model (SIMWE), m.

accurate. Linear discriminant analysis (LDA [13]), random forest (RF [14]) and supported vector machine (SVM [15]) methods were used for soil-landscape relationships modeling. Usage of Fisher criterion and linear regression made it possible to rank calculated topographical factors by their contribution to the percentage of explained variance of the soil groups. Also, probabilities of each pixel belonging to each soil group were estimated. The analysis of these probabilities allows getting the most probable class of soils, definiteness of the prediction. Probability of soil classes is measured as their proportion from the area of the pixel. The STATISTICA program was used for modeling by the LDA, whereas modeling by RF and SVM was implemented in RStudio.

3. Results

Among the set of derivative characteristics four covariates for interfluves and valleys were determined as significant. In case of LDA these factors are: valley index, channel network distance, depth of closed depressions and topographic position index (radius of 100 pixels). In valleys slope steepness, valley index and topographic position index (radius of 200 and 1900 pixels) were derived as factors of soil cover differentiation.

According to the list of covariates it is obvious that within interfluves the most important ones are the characteristics linked to soil water content that influence soils of an increasing series of hydromorphism formation: Ch → Mch → Mchg → soils of sinks. At the same time, the factor of lateral transfer and accumulation of material plays a decisive role in valleys. The overall accuracy of the models is 55.2% and 73.4% in interfluves and valleys respectively. Maps, which represent classes of the most probable soil structures, are shown in Figure 3.

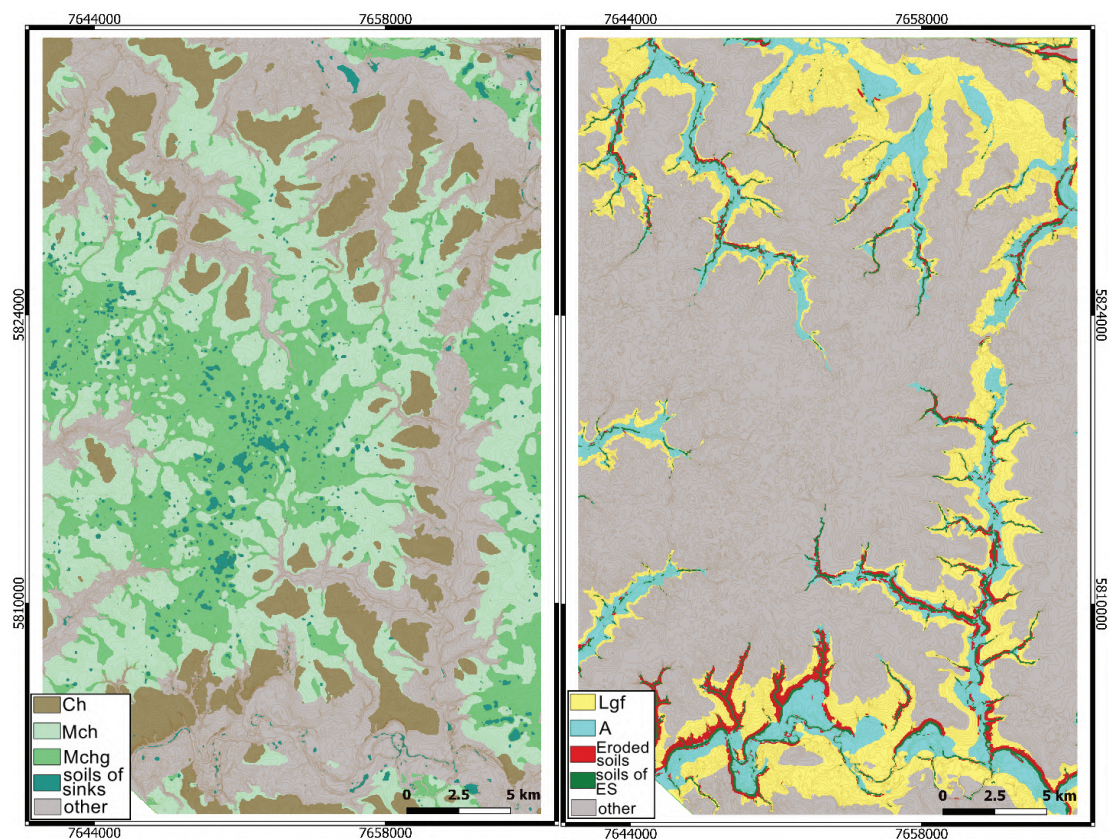


Figure 3: Results of simulation with linear discriminant analysis method (interfluve – left side, valleys – right side). ES – erosion systems.

The most definitive class within interfluves is Mch (51.1%) and Ch (50%) due to their clear position on flat surfaces with wide sinks and on well-drained elevated areas respectively. In valleys positions of soils of erosion systems (80.5%) were most accurately predicted in balkas (small dry or temporary watercourse U-shaped valleys with soddy slopes) and gulches whereas Lgf (66.7%) – on terraces.

In case of RF and SVM modeling methods, determinant covariates were not absolutely the same or their role in significance was different. Within interfluves such factors are a topographic position index (radius of 2100 pixels), channel network distance, slope steepness and a valley index. For valleys channel network distance, valley depth, slope

steepness and topographic position index (radius of 2100 pixels) were derived as factors of soil cover differentiation.

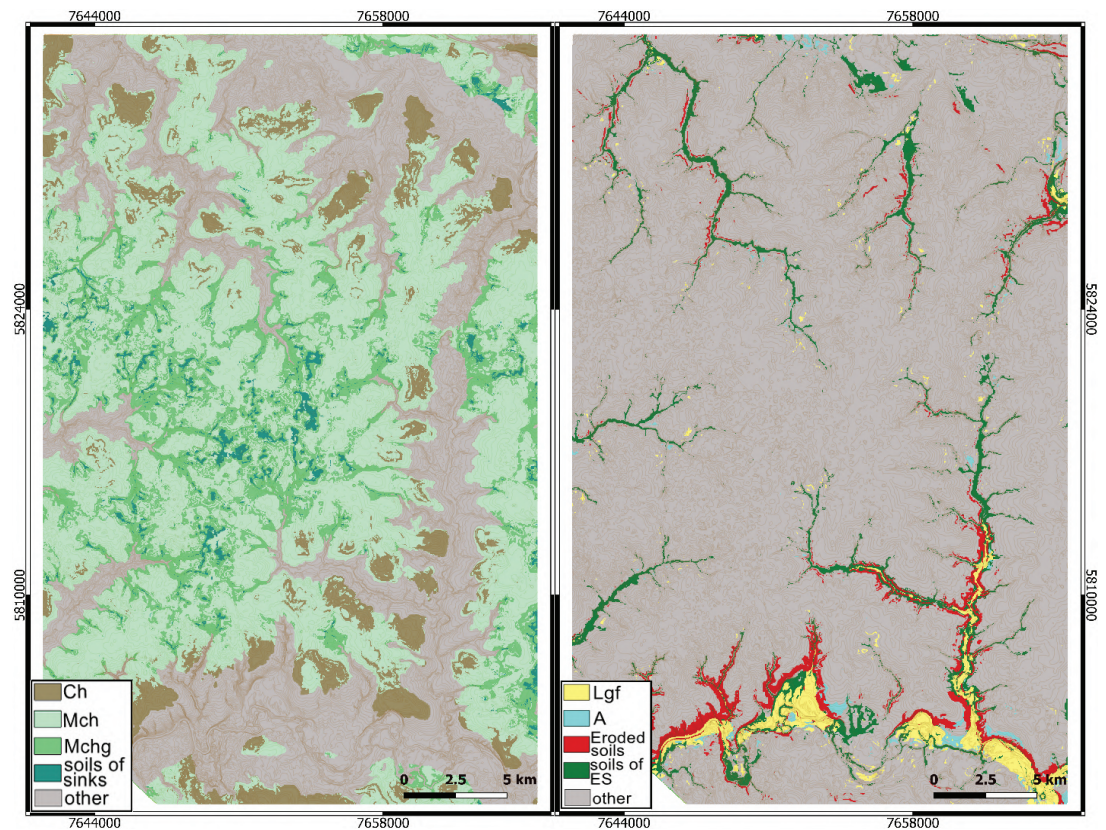


Figure 4: Results of simulation with random forest method (interfluvial – left side, valleys – right side).

The overall accuracy of models derived from RF simulation reaches 56.5% (within interfluvial) and 76.7% (within valleys). The most determinant predicted classes within interfluvial are Mch (76.7%) and Mchg (26.2%) located in flat areas and in shallow sinks with a zero or negative topographic position index values, whereas in valleys these classes are eroded soils (56.3%) located on steep slopes and soils of erosion systems (75.6%) situated in balkas and gulches. Results are shown in Figure 4.

Results of SVM modeling method are presented in Figure 5. The overall accuracy varies from 60.6% for interfluvial to 90% - for valleys. Soil classes with the highest precision value are the same as classes derived from the RF method. However, they differ in accuracy: 71.1% - for Mch, 42.3% - for Mchg, 85.4% - for soils of eroded systems and 81.3% - for eroded soils.

The comparison of three models was provided. The highest accuracy values have results of the SVM method, however the minimum range of them have results of LDA. The most important ones for agriculture soil classes within interfluvial are Mch due to the extra amount of humus and available soil moisture and soils of sinks, because

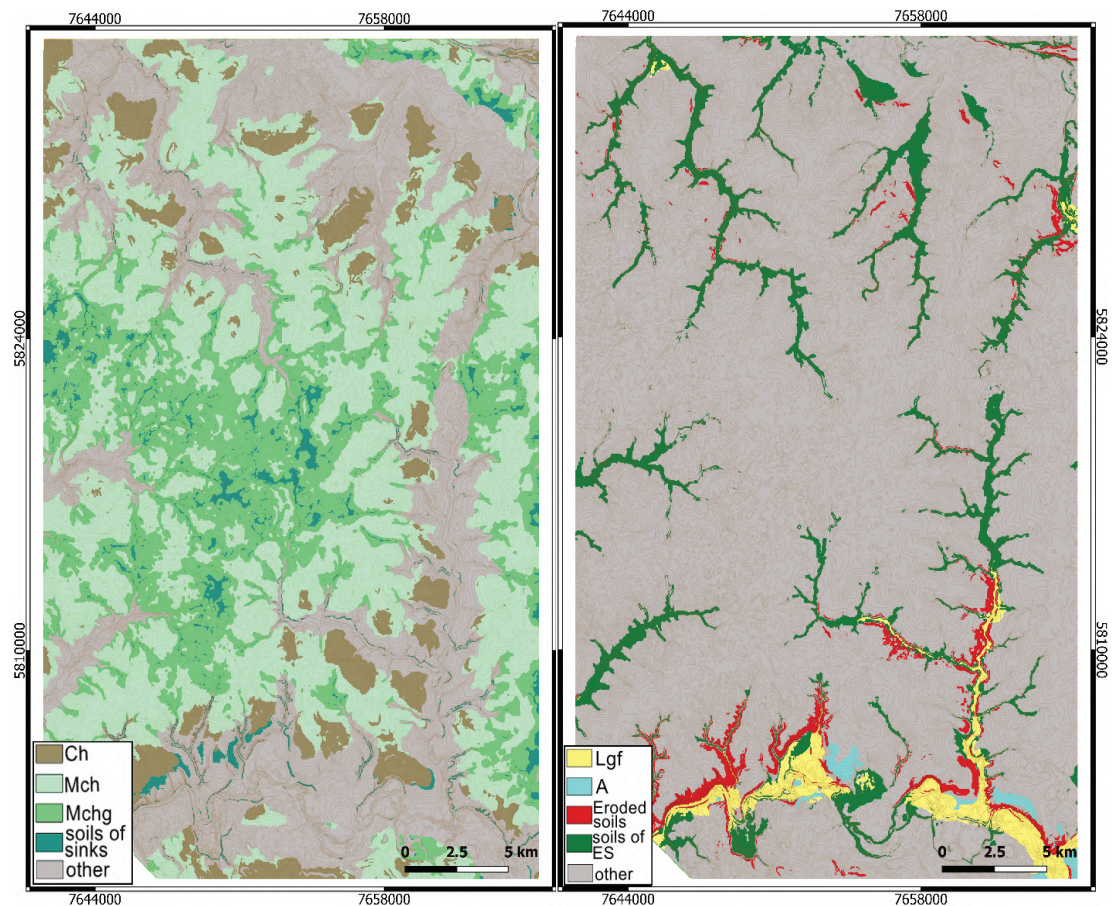


Figure 5: Results of simulation with supported vector machine method (interfluve – left side, valleys – right side).

they limit tillage and have an adverse water-air regime. RF and LDA methods could predict the position of Mch soils (76.7%) and soils of sinks (40.6%) respectively most precisely. In valleys Lgf and eroded soils become the most significant for prediction by the reason of the flat well-drained position of Lgf that can be used for plowing. As for eroded soils, contrariwise they limit agriculture on steep slopes. The position of Lgf class was predicted by the LDA method most accurately (66.7%), whereas eroded soils – by the SVM method (81.3%). The predicted composition of soil combinations was compared with detailed soil cover maps made on the basis of field surveys of 1988. It was estimated that the most precise results show the LDA method, especially in case of soils of sinks, Ch and Mchg classes.

Soil-agroecological types of lands were proposed (Table 1) on the basis of soil combinations and simulation results. An analysis of factors of differentiation and information about soil properties and their formation conditions allow distinguishing types of lands. Agroecological types of lands are considered as areas which are homogenous in terms of crop cultivation and management conditions (tillage and sowing methods are

differentiated in accordance with the elementary areas of the agricultural landscape – elements of the mesorelief with certain soil structures) and have similar agroecological requirements. They are used at the stage of landscape planning within landscape-adaptive agriculture systems [16], whereas planning takes into account the structure-functional organization of landscapes.

TABLE 1: The content of soil combinations and types of lands

Soil cover (Russian classification, 1988)	Soil cover (WRB, 2006)	Soil combinations	Agroecological types of land	Types of lands
Chernozems typical (Cht)	Voronich Chernozems pachic	Cht+Chl	Well-drained	Slightly convex loamy surfaces and gentle slopes (< 2°), well-drained, plowed
Chernozems leached (Chl)				
Meadow-chernozems (Mch)		Mch	Well-drained	Flat loamy (rarely clayey) slow-drained surfaces and wide shallow sinks with groundwater level on 3-6 m, underlain by moraine, plowed
Meadow-chernozems gleyed (Mchg)		Mchg+WMch	Semi-hydromorphic	Non-drained surfaces, wide sinks (20 cm depth), loamy (rarely clayey), with groundwater level on 1-3 m, underlain by moraine, plowed
Wet meadow-chernozems gleyed (WMch)				
Light-grey forest (Lgf)	Greyic Phaeozems Albic	Lgf	Well-drained	Flat sandy and sandy-loam terraces with groundwater level more than 6 m, with pine forests, partly plowed
Grey forest gleyic and gley (Gfg)		Gfg+Mb+Pb	Semi-hydromorphic/hydromorphic	Loamy sinks (max depth = 70 cm) with groundwater level on 1-2 m, underlain by moraine, with wet meadows, partly plowed

Soil cover (Russian classification, 1988)	Soil cover (WRB, 2006)	Soil combinations	Agroecological types of land	Types of lands
Meadow-boggy (Mb)	Haplic Gleysols Dystric			
Peats boggy (Pb)	Fibric Histosols Dystric			
Alluvials saturated (As)	Haplic Fluvisols Oxyaquic	As+Aa+Am	alluvial	Flat and slightly slanted loamy and sandy-loamy floodplains, with groundwater level less than 1.5 m, with riparian forests and wet meadows
Alluvials acid (Aa)	Umbric Fluvisols Oxyaquic			
Alluvials meadow (Am)	Umbric Fluvisols Oxyaquic			
Soils of erosion systems		Soils of erosion systems	Eroded	Loamy ravine-balka systems with wet meadows, partly forested
		Eroded soils	Eroded, lithogenic	Slopes (2 – 15°), loamy, somewhere with chalk and limestone outcrops, with meadows, partly plowed

4. Conclusion

The main reason of high uncertainty of soil-landscape relationships and low prediction values for some categories is associated with the natural complexity of soil cover. In addition, model accuracy depends on the set of covariates. The location and the form of «ecological niche» for every soil could be estimated via the range of their values within the space of SCORPAN factors. As the result of the study it was possible to identify the hierarchical nature of the SFO. Interfluves and valleys are derived on the first level of the structure. Their functioning is operated by water-migration and erosion-accumulative processes, respectively. On the second level within the interfluves the following structures are distinguished: non-drained and slow-drained surfaces, convex surfaces and depressions. In valleys on the second hierarchical structural level terraces, floodplains, slopes and erosion network are determined. Taking into account the

structural organization of the territory on a higher hierarchical level helps to predict the intensity of elementary soil and landscape-forming processes with greater accuracy and to identify the structural organization of the territory on a lower level. Nevertheless, the expert appraisal has significant value during the verification of soil-landscape correlation models and maps created on their basis.

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Conflict of Interest

The authors have no conflicts of interest.

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