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AGRICULTURAL CHEMISTRY AND SOIL FERTILITY

Experience in Reconstruction of Agricultural Land Use for Balakhna District of Nizhniy Novgorod Gubernia in the 18th–19th Centuries (on the Basis of Cartographic Sources)

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Abstract—Land use and soil cover patterns of arable lands in Balakhna district of Nizhny Novgorod gubernia in the last quarter of the 18th century and in the middle of the 19th century were studied with the use of the General Land Survey plan of Balakhna district (scale 1 : 84000), the map of Nizhny Novgorod gubernia by Mende (scale 1 : 42000), and the State Soil Map (scale 1 : 1 M). The data obtained attested to a steady and considerable decrease in the plowed area during that period. According to the historical materials, at the end of the 18th century, plowland occupied about 1290 km^2, or 32% of the entire district (4200 km^2). In the middle of the 19th century, the plowed area decreased to about 990 km^2 (25%). According to the modern statistical data on land use in Balakhna district (within its boundaries of the 18th–19th centuries), the area of plowed fields is less than 700 km^2 (18%). This means that at least 14% of the study area is occupied by the postagrogenic soils. If we take the plowed area of the district in the 18th century for 100%, we can conclude that more than 40% of formerly plowed lands have been transformed into long-term fallows. The absolute predomination of soddy-podzolic soils (Retisols) is typical of the soil cover of Balakhna district. In the course of the reduction of the plowland area from the end of the 18th century to the middle of the 19th century, the percent of different soils composing this area did not change much. In general, the impact of soil quality on the decrease in the plowland area in that period is not observed.

Keywords: land use, General Land Survey Plans, maps by Mende, soil cover, geoinformation system
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INTRODUCTION

In the recent millennia, our planet has been transformed significantly by human activities. Substantial impact of humans on nature and the need to study both natural and anthropogenic processes were noted by many scientists of the 19th century. Thus, E. Reclus, K. Ritter, and J. Marshall talked about the need for a universal geography that would consider the global impact of humans on nature [12, 27]. Similar thoughts were expressed by A. Gettner [6], who considered humans as a component of the natural landscape. In his chorological concept, he argued that the object of study in geography is the geographical space with its filling by interacting objects and phenomena, including human society.

The impact of human activity on the environment and, in particular, on soils, and the need to take into account the factor of human activity, was also described by Russian scientists, like V.V. Dokuchaev, and his followers and students G.N. Vysotsky, G.F. Morozov, L.S. Berg, V.N. Sukachev [5, 10, 20, 23], and many others. Thus, L.S. Berg spoke about the necessity to study not only natural but also cultural landscapes. In his work *Yergeni,* G.N. Vysotsky pointed to the dependence of steppe vegetation on human activity. G.F. Morozov in his *Fundamental of Forest Science* wrote about humans as one of the factors affecting life in the forest. V.N. Sukachev argued about the need to take into account natural changes and disturbances of all biogeocenotic components under the impact of human activities.

After attending lectures of V.I. Vernadsky in the early 1920s at the Sorbonne University in Paris, which later resulted in his concept of the biosphere and biogeochemical phenomena, E. Leroy and P. Teilhard de Chardin came to the idea of noosphere "as a modern stage, which is geologically experienced by the biosphere," when, as geologist A.P. Pavlov stated, a man "becomes a powerful and continuously increasing geological force" [4, p. 549], and with the onset of which the Earth "changes her skin" [24, p. 149].

The development of these ideas in the 21st century led to the introduction of the informal geochronological term Anthropocene, which means "a geological era with a level of human activity playing a decisive role in the state of the terrestrial landscapes of the Earth" [35]. Its authors Krutzen and Stormer point to a large-scale human activity, especially in the recent centuries. However, considering this period from the perspective of actual biogeography, Tishkov, on the basis of the Krutzen and Stormer criteria, relates the start of the Anthropocene as a new geological era for the territory of Northern Eurasia to the first centuries of our era with a time lag of several centuries in different regions; its advance was marked by the synergetic effect of frontal, simultaneous economic development of new territories [25, 26].

Many authors note the role of the agricultural activity of humans; its contribution to changes in the global carbon cycle has actively been studied [33, 36, 37]. Investigations into the historical dynamics of plowlands in different regions of the world attest to significant links between their changes and the social, political, and economic processes, including those in the modern period [31, 39, 40]. Thus, according to Pongratz et al. [38], Europe became one of the most important agricultural regions of the world in the early medieval period. Agricultural colonization developed rapidly until the14th century. Then, it ceased abruptly, and part of the land was abandoned due to a population decrease because of epidemics. In the 15th century, land transformation accelerated again and then stopped at the beginning of the 17th century because of a series of wars and economic crises. The rapid expansion of plowland in place of former forests predominated until the middle of the 19th century.

One of the indicators, or conditions for the development of the Anthropocene, is the irreversible transformation of the landscape, manifested, among other things, by the inherited agricultural fragmentation of the modern landscape. On the basis of his own research and the works of other geographers, biologists, and archaeologists Tishkov concluded about reaching of the maximum of agricultural development of the territory (much higher than that at present) in Eastern Europe in the 10th–15th centuries; in European Russia, this took place in the 8th–12th centuries [25, 26].

The study of the evolution of agrolandscapes in the nonchernozemic zone of the East European Plain—the main agricultural region of Russia for centuries—allowed Trapeznikova [28] to conclude that the agrarian landscapes in this zone were subjected to the most significant changes, including their almost complete disappearance in a number of regions. After the socioeconomic crisis of the 16th century in the northwestern and central regions of Russia, the population and the plowland area decreased dramatically, and a large number of abandoned arable land appeared instead of former settlements. A general decrease in the efficiency of Russian agriculture led to a new crisis in the middle of the 19th century, which was followed by crises at the beginning of the 20th century and in the 1990s. As a result of the latest crisis, the cropland area in Russia reduced by 18 million ha according to the official data and by 44.4 million ha (or by 22% of the total cropland area) according to calculations by Lyuri with coauthors [19].

A wider use of land for plowing in the past is also confirmed by the studies of postagrogenic soils in various parts of the forest zone [29, 34]. The features of former tillage are observed in the profiles of most of the forest soils for at least 170 years [19]. The portion of postagrogenic soils in the soil cover and their dynamics may be studied on the basis of data on land use patterns as displayed on cartographic materials of different periods.

The aim of our work was to study land use patterns in Balakhna district of Nizhny Novgorod gubernia (oblast) in the 18th and 19th centuries on the basis of the General Land Survey plans and maps compiled by Mende. We also studied the composition of the soil cover of arable lands and its changes during the 70-year-long period between the two surveys.

MATERIALS AND METHODS

Investigation area. Balakhna uezd (district) is a part of Nizhny Novgorod gubernia (oblast), which was chosen as an object of a number of ongoing works, since it was the first area studied by a special expedition supervised by V.V. Dokuchaev with the aim to make a more correct land assessment for taxation purposes. The materials of the expedition also served as the basis for the creation of the soil map of Nizhny Novgorod gubernia in 1886. Soil and land resources of this gubernia were thoroughly described. These materials, together with materials of the General Land survey and various soil maps were investigated by methods of geographic information systems [13, 14, 16, 17, 30].

From the beginning of the 18th century, when the Nizhny Novgorod gubernia was created, its boundaries have been subjected to numerous changes. In 1886 (in the year of creation of the first soil map of the gubrenia), it consisted of 11 uezds (districts). Balakhna district had an area of 4197 km^2 and was found on both banks of the Volga River in the northwestern part of the Nizhny Novogorod gubernia reaching the Oka River in the south. At present, this territory includes several administrative units: Balakhna, Chkalovka, and Gorodetskii districts; a part of Volodarskii district; and the cities of Nizhny Novgorod and Dzerzhinsk.

Land use data. In the Russian State Archive of Old Acts, a two-verst plan of Balakhna district developed during the General Land Survey of the 1780s–1790s

was discovered. There was also a one-verst map of Balakhna district developed by Mende in the 1850s.

General Land Survey was one of the largest and most ambitious mapping projects of the 18th century in the world; it was initiated in 1765 and continued until the revolution of 1917. Its purposes were to confirm land ownership rights; create land cadaster; study natural, demographic, and economic resources of Russia; register its historical monuments; and create large-scale maps.

The land surveying methods applied up to the end of the 18th century were somewhat outdated; in these works, neither cartographic projections not geographic coordinates were used. This caused certain difficulties in transformation of these materials into the vector format [15]. First, many paper originals were not in a good physical condition; they contained voids and because of the considerable duration of their storage. Second, as already mentioned, the plans of the General Land Survey did not have a mathematical basis; the boundaries of individual parts of the same plan did not coincide in some cases.

Plans for the territory of Nizhny Novgorod gubernia were created in the last quarter of the 18th century. The Balakhna uezd plan (scale 1 : 84000) consisted of three parts. The scanned materials were first prepared in the image editor software and then included in the GIS[1] and georeferenced to the boundaries of Balakhna uezd as shown on the *Soil Map of Nizhny Novgorod Gubernia* in 1886. Then, the raster images of the three parts of the plan were digitized; first, each part separately. Then, the three parts were combined using the affine transformations. It was found that the greatest errors on the old plan occur in the areas adjacent to the large Volga River [32]. To improve the accuracy, affine transformations were applied separately to the right-bank and left-bank territories, after which the harmonization of the boundaries was conducted. The essence of harmonization consisted of joining all the prepared parts of the Balakhna uezd into a single map.

Based on the plans of the General Survey and substantial mapping surveys conducted in the middle of the 19th century by military topographers under the supervision of general-major A.I. Mende, topographic land maps were created; later, they were referred to as the Mende maps [18]. The value of these cartographic sources is predetermined by the fact that they show land use categories, including those related to economic activities in a way analogous to that applied in the General Land Survey plans. However, the Mende maps were created with the use of cartographic projection and the geographic coordinate system. Although the survey was conducted in 21 central regions of Russia, maps were created for only eight them. Only the maps of Tver, Ryazan, and Tambov oblasts were officially published [3]. The maps for the remaining five oblasts (Yaroslavl, Vladimir, Nizhny Novgorod, Penza, and Simbirsk) were never fully completed; some map sheets contained "elements of unpainted black sketches" [3, 21].

Unlike the General Land Survey materials lacking the mathematical basis and projection, the Mende maps have these two important characteristics. During the General Land Survey materials, surveyors were concentrated on setting the boundaries land allotments, whereas information inside them was shown not so accurately, or just schematically. Unlike this, the military topographers aimed for the accurate representation of all the objects on the territory. The newly appeared coordinate grid also increased the accuracy of these maps.

Nizhny Novgorod gubernia on the Mende map is divided into squares represented by separate sheets of the map on a scale of 1 : 42000. The territory of Balakhna district is found within 21 squares. During the preparation of a raster image, the squares were combined in an image editor software. Then, they were georeferenced in the GIS according to the boundaries of Balakhna uezd as displayed on the Soil Map of Nizhny Novgorod gubernia 1886. Then, the raster images were digitized.

The legend to the Mende map for Nizhny Novgorod gubernia is somewhat more detailed than the legends of the General Land Survey plans. Some necessary information to interpret the map can be found in notes directly on the map sheets. It should be noted that the color depicting different land categories on the map somewhat varies from sheet to sheet, which may be related to the initial preferences of cartographers, the conditions of map storage, the age of the sheets, and the scanning method [3]. In some cases, these differences complicate understanding of the displayed information.

Various forestlands were separated on the maps: building wood, firewood, wood growing in swamps, and shrubby wood. In addition to these criteria, the color of forestlands also reflected the species composition of tree stands (pine, spruce, deciduous, or mixed forests). Thus, violet tints were applied to depict spruce forests; pink tints, pine forests; brown tints, mixed forests; and grayish blue tints, deciduous forests. Hatching superposed over these colors indicated the growth of the trees on boggy territories.

In addition to forest plantations, the Mende maps depicted mires separated into "clear" mires and mires with shrubs. Plowland was shown by beige color. Several types of floodplain were separated: sandy floodplain (light brown color with dark brown dots), "clear" (barren) floodplain (light green), and floodplain with vegetation (light green background color with dark green inclusions). Meadows were subdivided into four types: proper meadows, meadows with shrubs, wet meadows, and wet meadows with shrubs.

[1] The work was performed using MapInfo v.10.5 – 12.5 software.

Table 1. The composition of the soil cover of Balakhna district according to the SSM (1953)

Soil name	Area, % (on a waterless territory)
Soddy slightly podzolic sandy soils	27.0
Soddy moderately podzolic light loamy silty soils on the covering deposits	6.1
Soddy moderately podzolic light loamy sandy soils on the moraine	6.5
Soddy moderately podzolic loamy sandy soils	9.4
Soddy moderately podzolic sandy soils	5.7
Soddy strongly podzolic light loamy silty soils on the covering deposits	6.2
Soddy strongly podzolic light loamy sandy soils on the moraine	12.8
Soddy strongly podzolic loamy sandy soils	2.6
Soddy strongly podzolic loamy (shallow) soils underlain by sands	0.3
Soddy podzolic gleyic sandy soils	3.6
Peat soils	13.3
Alluvial (floodplain) soddy soils	6.5

The colors for these lands varied from light green to dark green with hatching.

In the course of our study, we generalized initial information. The following land categories were identified: forest, swampy forest, bog, plowland, sandy floodplain, floodplain, hayfield, water objects, roads, and settlements.

Data on soils. Most of the former Balakhna district is located within the zone of soddy-podzolic soils of the southern taiga, and its southern part enters the zone of gray forest soils of deciduous forests [11]. According to the classification of soils of Nizhny Novgorod gubernia [22] applied for the map of 1886 (scale 1 : 420000), four soil groups were separated in Balakhna district in the type of "Northern" soils (light loams, loamy sands, clayey sands, and quartz sands (soils under pine forests)); in addition, the map shows the areas of bog soils and floodplain soils. The largest territory is occupied by quartz sands (33%) followed by light loams (32%). Clayey sands occupy 13%, and loamy sands occupy only about 3%. The areas of bog and floodplain soils constitute 10 and 9% of the entire territory, respectively.

There are soil maps on the investigated territory created in different years and on different scales. In the course of previous works, we digitized the following maps: *Soil Map of Nizhny Novgorod Gubernia* (1886, 1 : 420000), *Soil Map of Balakhna Uezd* (1894, 1 : 420000), and a fragment of the *State Soil Map (SSM) of the Soviet Union* (1953, 1 : 1 M) on the territory of Nizhny Novgorod oblast. In addition, we used the digitized version of the *Soil Map of the Russian Federation* (1988, 1 : 2.5 M)[2]. These maps were used to study representation of the soil of Nizhniy Novgorod oblast on the maps of the 19th–20th centuries [1, 2]. The comparison of the maps indicated that recent soil maps generally inherit information on the soil cover from the Soil Map of the Nizhny Novgorod Gubernia, one of the first soil maps in Russia, for which the genetic classification of soils was applied. Despite a smaller scale of the modern maps of 1953 and 1988 and a smaller number of delineated soil polygons, the soil cover of the investigated territory on them is represented by a larger number of different soils. We also found that the water surfaces on the maps of 1886 and 1953 occupy only 0.8% of the territory of Nizhny Novgorod oblast, whereas on the map of 1988, their area increased to more than 3%, which may indicate a change not only in the soil cover but also in the hydrographic regime of the region as a result of the construction of dams. The great Gor'kii Water Reservoir on the Volga River was filled in 1955–1957 and totally changed the territory. Human life in this area was concentrated around the Volga River, and there were many settlements on its banks that were submerged under water. Taking this into account, we analyzed the composition of the soil cover of arable lands in Balakhna district on the basis of SSM published in 1953 (before filling of the reservoir).

The territory of Nizhny Novgorod oblast lies within three sheets of the SSM: N-37, N-38, and O-38 [7–9]. According to this map (Fig. 1, Table 1), 80% of the area of Balakhna district is occupied by various soddy-podzolic soils (Retisols) with a predominance of relatively coarse-textured soils. The remaining 20% of the territory is occupied by peat soil (Histosols) and alluvial soils (Fluvisols).

On the basis of the digitized SSM sheets, we calculated the percentage of different soils for arable (plowed) land as shown on the General Land Survey maps of the 18th and 19th centuries.

[2] Soil Map of the Russian Soviet Federal Socialist Republic, scale 1 : 2.5 M, ed. by V.M. Fridland. Moscow: GUGK, 1988, Digitization of the map was performed by specialists from the V.V. Dokuchaev Soil Science Institute.

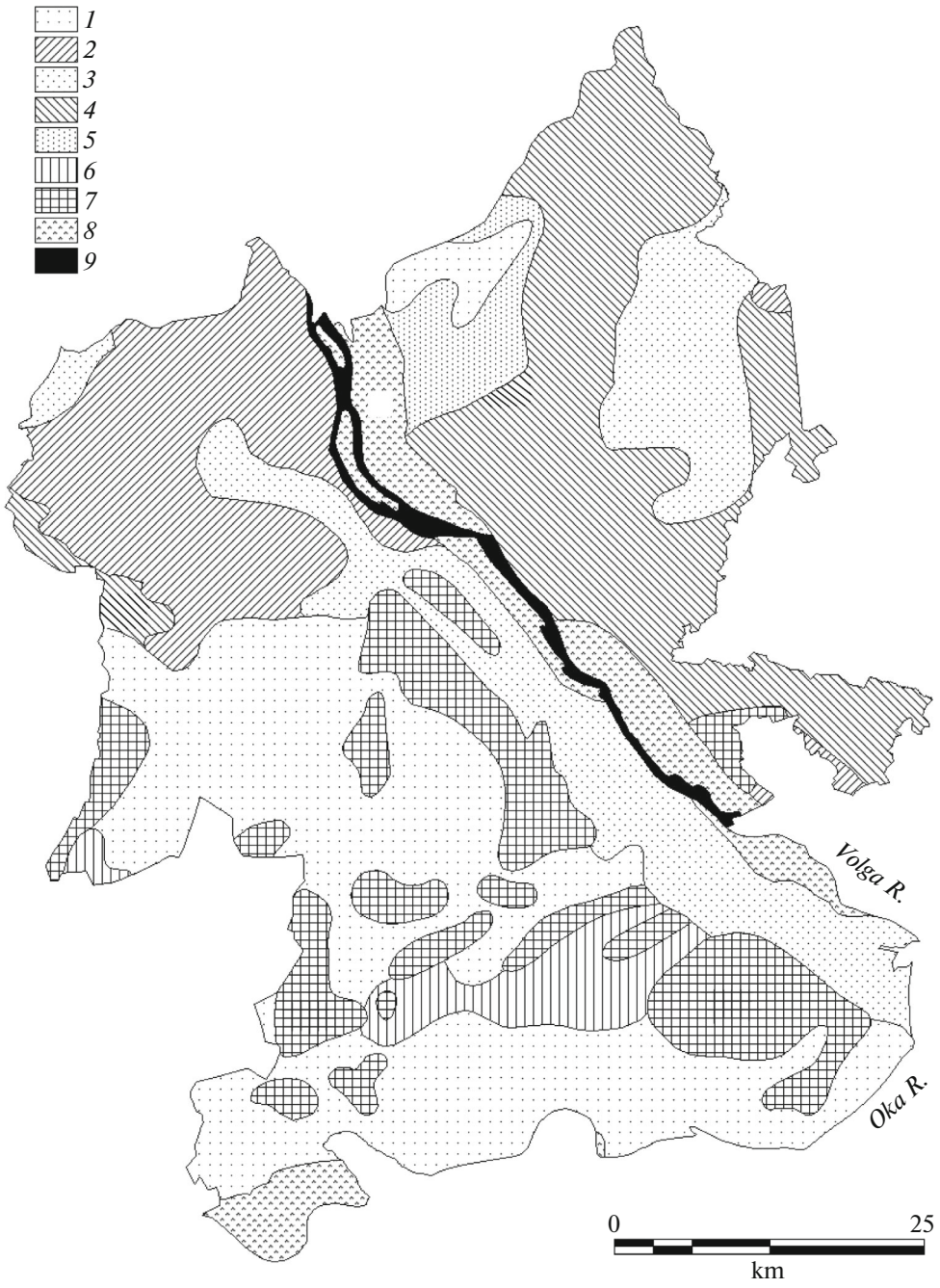

Fig. 1. Soil cover of Balakhna district as displayed on the SSM (1953–1955). Soils: (*1*) soddy slightly podzolic sandy, (*2*) soddy moderately podzolic light loamy, (*3*) soddy moderately podzolic loamy sandy and sandy, (*4*) soddy strongly podzolic loamy, (*5*) soddy strongly podzolic sandy loamy, (*6*) soddy-podzolic gleyic sandy, (*7*) peat, and (*8*) alluvial (floodplain) soddy soils; (*9*) water bodies.

RESULTS AND DISCUSSION

Lands of Balakhna uezd (district). The work with plans and maps containing information on land areas allowed us to judge land use patterns in Balakhna district. The map of Balakhna district lands created in the second half of the 18th (according to the plans of the General Land Survey), is shown in Fig. 2. More than 50% of the territory is under forests (forests proper and floodplain forests); 11% of the territory is under bogs (Table 2). About 1290 km^2, or almost one-third of the total area is occupied by plowland, mainly in the northern part of the district.

On the Mende map, forestland—forests and wet forests—is insignificantly (by 4%) larger in comparison

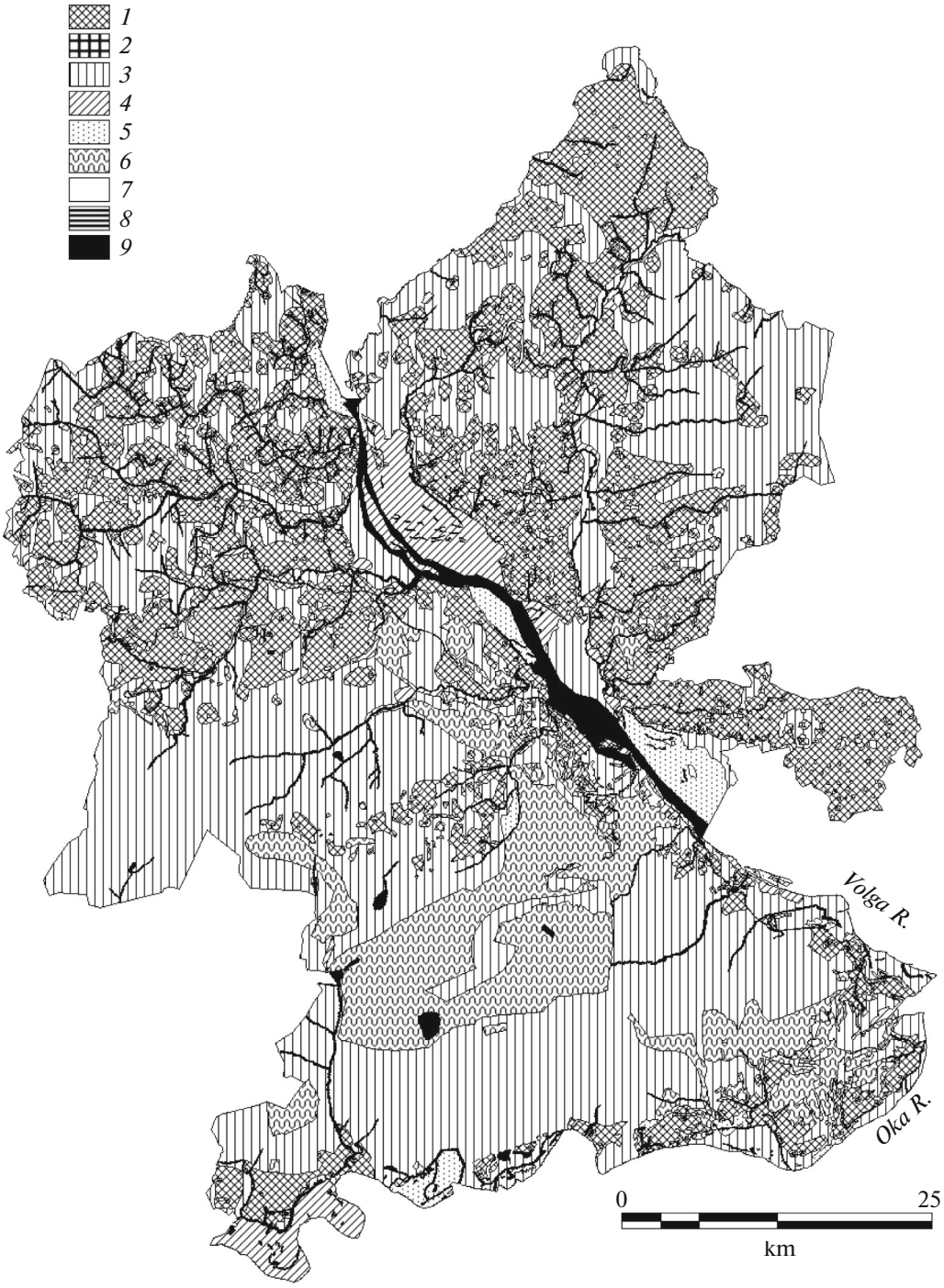

Fig. 2. Land use in Balakhna district in the 18th century: (*1*) plowland, (*2*) hayfield, (*3*) forest, (*4*) floodplain forest, (*5*) sandy floodplain, (*6*) bog, (*7*) settlements, (*8*) roads, and (*9*) water bodies.

with that on the General Land Survey plans (Fig. 3, Table 2). The area of bogs is approximately the same. The territory occupied by hayfields, settlements, and roads is somewhat larger. The Mende map depicts floodplain and sandy floodplain areas; taken together, they occupy 5%. On the General Land Survey plans, floodplain forests and sandy floodplains occupy less than 5.7% of the territory.

According to the of Mende map, plowland in the middle 19th century occupied 990 km^2, or about 25% of the district area. Thus, one-fifth of the plowland shown on the maps of the 18th century disappeared from the new map. Such a significant reduction means that formerly plowed soils on the area of 300 km^2 passed into the category of postagrogenic soils.

Table 2. Land use patterns in Balakhna district in the 18th, 19th, and 21st centuries

According to the General Land Survey plans (18th century)		According to the Mende maps (19th century)		According to statistical data (21st century)	
land use	area, % (on the waterless territory)	land use	area, % (on the waterless territory)	land use	area, % (on the waterless territory)
Plowland	32.3	Plowland	25.2	Plowland (+ fallow)	18.4
Hayfield	0.1	Hayfield	0.3	Hayfield	2.9
Forest	49.3	Forest	44.5	Forest land	53.7
Floodplain forest	3.8	Wet forest	11.9	Bogs	2.2
Sandy floodplain	1.9	Floodplain	4.4	Lands under buildings	7.6
Bog	11.1	Sandy floodplain	0.6	Under roads	3.0
Settlements	1.4	Bog	11.2	Other lands	12.1
Roads	0.2	Settlements	1.7		
		Roads	0.3		

Figure 4 shows the decrease in the areas of plowland during seven decades that passed between the creation of the two map sources used in our study.

It is interesting to compare these historical data with modern information on the land use. The latter was obtained not on the basis of the modern land use map, but via recalculation of official statistical data on land uses in the administrative subjects of the Russian Federation as of January 1, 2006 (information from the federal state statistical observation of land resources carried out by the Federal Real Estate Cadaster Agency) with the help of GIS software for the territory of the former Balakhna uezd (Table 2).

Approximate calculations (without taking into account the actual location of the land) showed that the total area of arable land (plowed fields and fallow lands) in 2005 comprised about 700 km^2 in the former Balakhna uezd, or 18.4% of its territory. Thus, in two and a quarter centuries that have passed since the General Land Survey in Balakhna uezd, the area of arable land has decreased significantly. At the same time, the area of hayfields has increased. As for pastures and perennial plantations that are considered separate types of agricultural land use at present, they were not separately depicted on land use maps of the 18th century. Presently, forestlands occupy about 50% of Balakhna district, and their area is approximately the same as that in the period of the General Land Survey. Bogs were shown as a separate land group on the plans of the General Land Survey; in the economic notes to these plans, they were referred to as "uncomfortable" lands; they occupied about 11% of the territory. Their area has decreased significantly at present, which may be due to the active reclamation measures. A significant increase in the area occupied by roads and buildings should also be noted.

In addition to these land use categories, several other categories are distinguished at present in statistical reports. However, they were not reflected in the earlier statistical forms. In Table 2, they are shown as "other lands."

The composition of the soil cover of plowland in Balakhna district. The areas of different soils composing plowland in Balakhna district in the 18th and 19th centuries were calculated according to the State Soil Map on a scale of 1 : 1 M. On this map, these soils include soddy slightly podzolic, soddy moderately podzolic, soddy strongly podzolic, and alluvial soils.

In our calculations, we did not take into account soil texture classes shown on the State Soil Map. This was mainly related to the insufficient accuracy of the plans of the General Land Survey and the need to correct the results in the GIS.

The calculations showed that the total area of plowland in the district decreased by nearly 300 km^2. This decrease mainly took place in the areas of soddy moderately podzolic and strongly podzolic soils. The area of cultivated soddy slightly podzolic soils and, also, alluvial soils somewhat increased. However, we should carefully apply the obtained data on the alluvial soils, because, as noted above, the greatest errors on the plans of the General Land Survey were found for the areas adjacent to the river and occupied by alluvial soils.

The changes in the percentage of different soils composing plowland were not very significant: the portion of soddy strongly podzolic soils remained unchanged, the portion of soddy moderately podzolic soils decreased by 11%, and percentage of soddy slightly podzolic soils increased at 8% (Table 3).

According to Trapeznikova [28], under conditions of arable farming in the forest zone of the East European Plain, the proximity of the arable land to a settlement was a more significant factor for peasants than the natural fertility of the soils; therefore, in the case of plowland shortage, the area of plowed soils was expanded at the expense of less fertile but closely

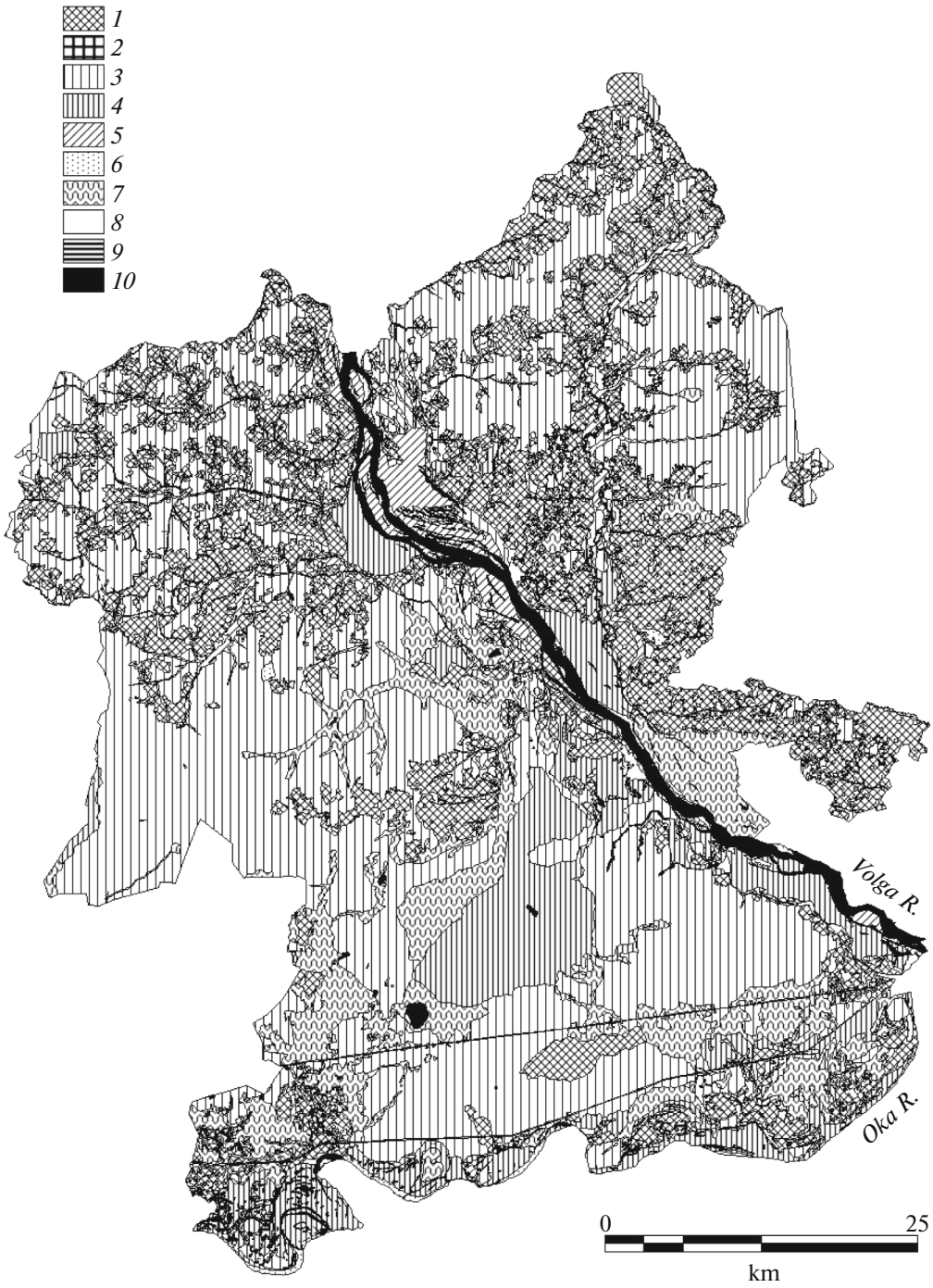

Fig. 3. Land use in Balakhna district in the 19th century: (*1*) plowland, (*2*) hayfield, (*3*) forest, (*4*) wet forest, (*5*) floodplain, (*6*) sandy floodplain, (*7*) bog, (*8*) settlements, (*9*) roads, and (*10*) water bodies.

Table 3. The composition of the soil cover of plowland in Balakhna district

Soils according to the SSM	Area in the 18th century		Area in the 19th century		Changes in the area	
	km^2	%	km^2	%	km^2	%
Soddy slightly podzolic	137	10.7	188	19.1	51	8
Soddy moderately podzolic	550	42.8	312	31.6	−238	−11
Soddy strongly podzolic	567	44.1	435	44.0	−132	−0
Alluvial	32	2.5	53	5.4	21	3

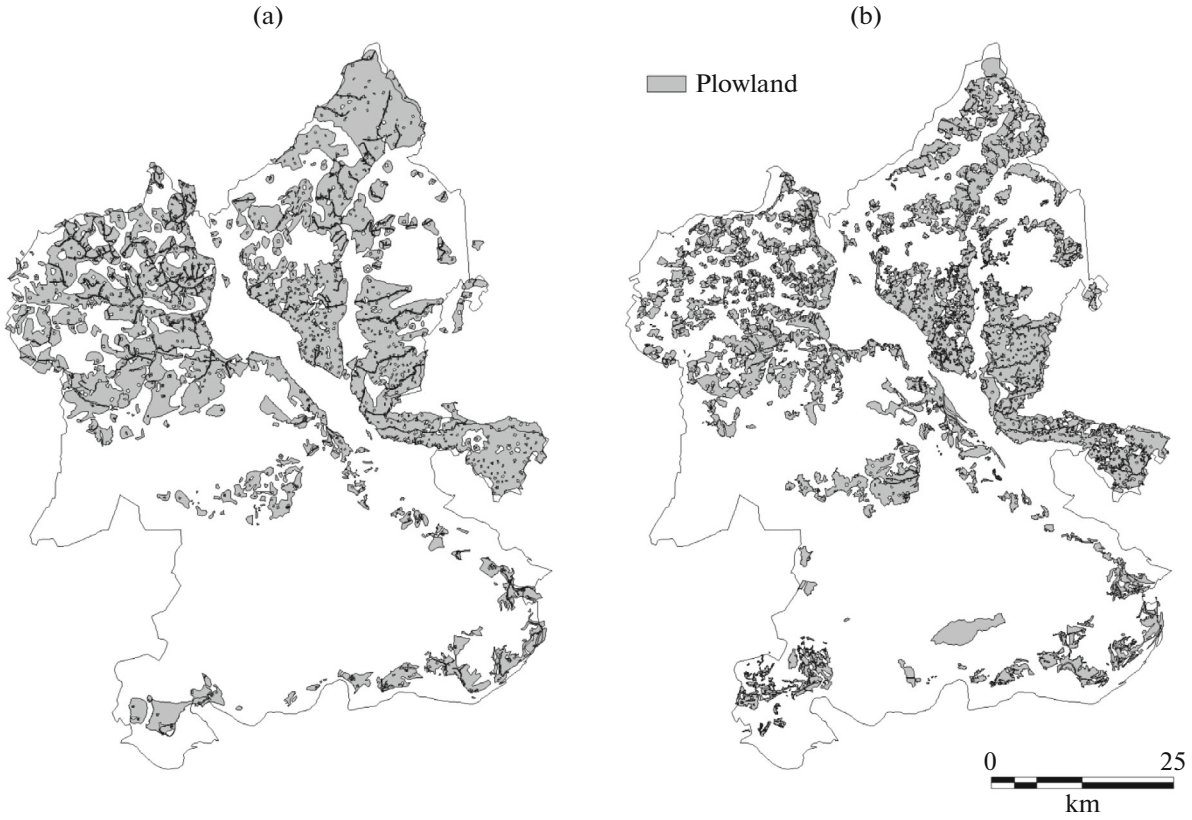

Fig. 4. Plowland areas in Balakhna district in the (a) 18th and (b) 19th centuries.

located lands. It is obvious that plowlands were withdrawn from their because of various reasons with the major factor of the distance from the permanent settlement; soil quality was often disregarded in this case.

CONCLUSIONS

The obtained data on the history of land use in Balakhna district of Nizhny Novgorod oblast attest to a steady tendency for decrease in the plowland area within the past two and a half centuries; the same tendency has been noted for other regions of the forest zone [19]. According to the statistical data and historical maps used in our work—the plans of the General Land Survey and the maps by Mende—the plowland area in the investigated territory has decreased by almost two times during this period. At the end of the 18th century, it comprised about 1290 km^2; in the middle of the 19th century, 990 km^2; at the beginning of the 21st century, less than 700 km^2. The percent of plowland in the total area of the district (4200 km^2) comprised 32, 25, and 18%, respectively. In other words, at least 14% of the study area is composed of postagrogenic soils. If we take the plowland area in the 18th century at 100%, it reduced to 78% in the middle of the 19th century and to 57% at the beginning of the 21st century.

The study of different soils composing the plowland in Balakhna district showed that their ratio (in percent) has changed insignificantly. In general, the effect of the soil quality on the decrease in the plowland area for the studied period is insignificant. This confirms the conclusion made by Trapeznikova for the forest zone of the East European Plain: under conditions of arable farming, the proximity of plowed fields to a settlement is a more significant factor than the natural fertility of soils [28].

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