The Analysis of Spatial Propagation of the Key Degradation Processes in the Farmlands of Samarskaya Oblast

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Abstract. This work deals with the spatial analysis of farmland degradation in Samarskaya Oblast. The degree of degradation was evaluated pro rata with the yield shortfall caused by the environmental condition of the lands and the diminishing of their fertility. We classified the lands by their degradation levels, zoned them across administrative districts, and assessed the fertility fall coefficient. We proved the feasibility of differentiating approaches to the recovery of land fertility and soil protection.

1. Introduction

The environmental condition of lands, especially surface soils, is constantly under change. This happens due to exogenic dynamic processes (the impacts of the wind and surface water supply), the changes in the hydrological regime (seasonal floods, stagnation of water in accumulating reliefs), the influence of bedrocks on soil formation, and other factors. The agricultural impacts on the cultivated land provoke greater in the topsoil. The fertility of the land is sufficiently decreased or lost because rates of systematic use of soil resources exceed their natural recovery rates.

According to the Soil Improvement Department of the Russian Ministry of Agriculture, the overall land area of the farmlands suffering from erosion alone is 120 million ha [1]. The losses reach 3.2-3.9 million tons of agricultural produce in grain equivalent, and the overall damages are estimated at 18-25 billion rubles a year [2]. The irrational use of farmlands (excessive watering, using the water with the high content of salts), canalization of rivers, and reservoir construction also provoke topsoil changes that sometimes lead to salinification and alkalinization of soils, as well as waterlogging and bogging.

Significant efforts and material inputs are required to recover soils and prevent their degradation [3]. Alternative methods may include justified decisions on the withdrawal of the lands concerned from the operations. The information bases for such projects include the soil inspection data, environmental monitoring of lands, comprehensive analysis of natural properties, and degradation rates.

Large-scale soil and geobotanical research were conducted in Russia in 1992-2000 [4]. The state record of land fertility was performed in 2002-2004 [5]. We obtained change maps for topsoil parameters (permeability, soil material, damaged areas, roughness, groundwater levels, etc) [6].
allows us to identify the geographic development patterns of adverse environmental processes and determine the degree of soil disturbance in terms of its parameter changes.

The results show that the key process determining the environmental condition of the topsoils in Samarskaya oblast is water erosion [7]. Wind erosion and the water-salt imbalance (overwatering, waterlogging, and bogging, salination, salt lake, and black alkali soil formation), and stone clogging are less prominent and more local in soil drifting.

Soil erosion is very harmful to both agriculture and the national economy as a whole. It leads to soil degradation and farmland reduction, as well as the decrease in the potential fertility of soils and their chemical and agrophysical parameters, water regime, biological and fermentation activity, and, as a result, the reduction of yields and product quality. The damages in Samarskaya oblast associated with erosion due to the loss of humus, nutrients, and water discharge amount to about 2 billion tons in grain equivalent, i.e. the yield shortfall in the region is between 0.4 and 0.6 tons per hectare [8].

This data is insufficient to justify the actions to recover soil fertility and soil protection projects. They call for an evaluation of the degradation of land as a means of agricultural production [9] expressed in natural or economic parameters. Thus, the degree of degradation shall be expressed pro rata with the yield shortfall caused by the environmental condition of the lands and the diminishing of their fertility.

The goal of this work is to conduct a spatial analysis of farmland degradation in Samarskaya oblast and evaluate the fertility fall coefficient impacted by adverse factors. The objectives include the classification and zoning of disturbed lands across administrative districts, the assessment of fertility fall coefficient, and the differentiation of soil fertility recovery and soil protection approaches.

2. Conditions and methods

Samarskaya oblast is located in the south-eastern part of the East European (Russian) Plain, in the middle reaches of the Volga river, which divides its territory into the right-bank and left-bank parts. The right-bank part includes the Volga Upland, a high plateau dissected by a network of coombes, gulches, and rivers, and the Zhiguli swell [11]. The left-bank part (Zavolzhye) is characterized by rugged, high-rolling terrain gradually elevating towards the East and turning into a rolling upland of the eastern edge of the Russian Plain. It includes the Bugulma-Belebey Upland in the north-east of Samarskaya oblast, and the spurs of the Obshchy Syrt to the south of the Samara river, which is the western slope of the South-Ural ridge.

Despite the presence of a large waterway, the Volga, Samarskaya oblast, and especially its steppe and dry steppe areas, have insufficient surface water. The key constituents of the surface water in the region include permanent and periodic rivers and brooks, occasional streams in coombes and gulches, small lakes, and rare swamps. We should specifically mention the system of artificial water bodies: the Kuybyshev and Saratov reservoirs, as well as irrigation and drainage ditches found mostly in the southern districts that have scarce natural water sources.

The oblast climate is moderately continental with hot summers, long and cold winters, insufficient moisture, moderately intensive winds, and relatively high exposure to the sun [12]. The warm period (with air temperatures over 10ºC) lasts 135-150 days. The aggregate heat sources of the territory over this period fluctuate between 2200° and 2800°. The north and the west of the oblast see the most precipitation (up to 450 mm). Southern steppe districts see the least precipitation (270-300 mm). During the summer, there are often droughts (frequency of about 50%) and dry hot winds (16-25 days a year). In winters, there is usually a stable snow cover from 22 cm in the south and the south-east to 46-52 cm in the north-western districts. Springs typically feature a rapid increase in temperatures, fast melting of the snow cover, and mass flooding of rivers.

Black soil types are dominant in the region (97.5% of all arable land). Their distribution across the region complies with the zoning laws, and their fertility gradually decreases from north to south [13, 14].

The differences in the latitudes of the soil and climate resources underlie the zoning of Samarskaya oblast. It features three natural agricultural zones: the forest-steppe, steppe, and dry steppe. The forest-
steppe covers the entire area on the right bank of the Volga and a part of the left bank to the north of the confluence of the Samara and the Bolshoy Kinel (Figure 1). It is characterized by fertile black soils (mostly the typical and leached varieties) and a water-and-heat balance that is well-suited for agriculture. The steppe zone is located to the south of the previous one, and it features typical and occasionally southern black soils. Its climate is drier due to the reduction of atmospheric moistening and higher temperatures. The dry steppe begins to the south of the Bolshoy Irgiy and Karalyk rivers. It features less fertile southern black and chestnut soils, and its climate is the harshest.

Various combinations of landscapes and soil and climate resources create diverse conditions for production activities and the disturbance of the environmental state of the soils. As a result, the type of changes and soil disturbance levels vary across territories depending on the climate zones and administrative districts they are in.

The evaluation methods for farmland degradation [15, 16] require that each of the region's administrative districts was assigned a degradation level and a score (0 to 5) for each of the anthropogenic impacts depending on the yield shortfalls for winter wheat as the dominant crop in the oblast (Table 1). A shortfall of 50% or more was considered to signify disastrous damages.

| Score and degradation features | Negative impact types | Negative impact set |
|-------------------------------|-----------------------|---------------------|
| 0 insignificant               | erosion: less than 12 | water-salt imbalance: less than 8 | stone clogging: less than 10 | less than 12 |
| 1 low                         | 12-24                 | 8-16                | 10-20                | 12-24         |
| 2 medium                      | 24-36                 | 16-24               | 20-30                | 24-36         |
| 3 high                        | 34-48                 | 24-32               | 30-40                | 34-48         |
| 4 very high                   | 48-60                 | 32-40               | 40-50                | 48-60         |
| 5 disastrous                  | 60 or more            | 40 or more          | 50 or more           | 60 or more    |

**Figure 1.** Natural and agricultural zones of Samarskaya oblast.
3. Results and discussion

According to the data [7], 26.6% of the farmland in Samarskaya oblast suffers from water erosion of various levels (low, medium, high), and its area is still growing [5]. Currently, it amounts to 765 thousand ha or 29.7%. Water erosion is observed in all of the administrative districts of Samarskaya oblast, and it impacts between 1.5 and 50% of the farmland area.

The proportion of farmland with soils suffered from wind erosion is low (0.7%), but about 50% of the farmland is vulnerable to it. The highest soil drifting parameters were observed in Syzranskiy, Shigonskiy, and Privolzhskiy districts (5-7%), where soils feature large proportions of sand and sandy clay, which are easily blown by the wind.

According to the methods used, the level of soil degradation due to erosion can be assessed within a range of 0 to 4 points (Table 2, sketch map on Figure 2a). Disastrous damages (5 points) were not observed in any of the districts.

Table 2. The degradation of farmland in Samarskaya oblast due to a set of negative impacts.

| Administrative district | Degradation score | Fertility fall coefficient in rel. units. |
|-------------------------|-------------------|----------------------------------------|
|                         | Erosion           | Water-salt imbalance | Stone clogging | Erosion | Water-salt imbalance | Stone clogging |
| Chelnovershinskiy       | 2                 | 1                       | 0          | 0.98   | 0.99                 | 1.00           |
| Shentalinskiy           | 2                 | 0                       | 0          | 0.97   | 0.99                 | 0.999          |
| Klyavlnskiy             | 2                 | 0                       | 0          | 0.97   | 1.00                 | 0.998          |
| Koshkinskiy             | 2                 | 1                       | 0          | 0.98   | 0.99                 | 1.00           |
| Segriyevskiy            | 3                 | 1                       | 0          | 0.97   | 0.99                 | 0.999          |
| Isaklninskiy            | 2                 | 1                       | 0          | 0.97   | 0.99                 | 0.999          |
| Kamyshinskiy            | 4                 | 0                       | 1          | 0.96   | 1.00                 | 0.997          |
| Elkhovskskiy            | 2                 | 0                       | 0          | 0.98   | 1.00                 | 1.00           |
| Pokhvistnevskiy         | 4                 | 0                       | 1          | 0.96   | 1.00                 | 0.998          |
| Syzranskiy              | 2                 | 0                       | 0          | 0.97   | 1.00                 | 0.999          |
| Shigonskiy              | 3                 | 0                       | 0          | 0.97   | 1.00                 | 1.00           |
| Stavropolskiy           | 1                 | 0                       | 0          | 0.99   | 0.99                 | 1.00           |
| Krasnoyarskiy           | 1                 | 1                       | 0          | 0.98   | 0.99                 | 1.00           |
| Kinel-Cherkasskiy       | 3                 | 0                       | 0          | 0.97   | 1.00                 | 1.00           |
| Privolzhskiay           | 0                 | 1                       | 0          | 0.99   | 0.99                 | 1.00           |
| Bezenchukskiy           | 0                 | 1                       | 0          | 0.99   | 0.98                 | 1.00           |
| Volzhskiay              | 1                 | 1                       | 0          | 0.98   | 0.99                 | 1.00           |
| Kinelskiay              | 1                 | 1                       | 0          | 0.99   | 0.99                 | 1.00           |
| Bogatovskiy             | 0                 | 0                       | 0          | 0.99   | 0.99                 | 1.00           |
| Borskiy                 | 1                 | 0                       | 0          | 0.99   | 1.00                 | 1.00           |
| Khvorostyanskii         | 0                 | 0                       | 0          | 0.99   | 1.00                 | 1.00           |
| Krasnoarmeyskiy         | 2                 | 0                       | 0          | 0.98   | 1.00                 | 1.00           |
| Neftegorskiay           | 1                 | 0                       | 0          | 0.99   | 0.99                 | 1.00           |
| Alekseyevskiy           | 2                 | 0                       | 0          | 0.98   | 0.99                 | 1.00           |
| Pestravskiy             | 2                 | 0                       | 0          | 0.98   | 0.99                 | 1.00           |
| Bolsheglushitskiy       | 1                 | 0                       | 0          | 0.99   | 0.99                 | 1.00           |
| Bolshechemigovskiy      | 3                 | 1                       | 0          | 0.97   | 0.97                 | 1.00           |
| Oblast as a whole       | 2                 | 0                       | 0          | 0.98   | 0.99                 | 1.00           |
Figure 2. The degradation scores for the farmlands of Samarskaya oblast caused by erosion (a), water-salt imbalance in soils (b), and stone clogging (c).

(Administrative districts: 1 – Chelnovershinskiy, 2 – Shentalinskiy, 3 – Klyavlinskiy, 4 – Koshkinskiy, 5 – Sergiyevskiy, 6 – Isaklinskiy, 7 – Kamyshlinskiy, 8 – Yelkhovskiy, 9 – Pokhvitnevskiy, 10 – Szynanskiy, 11 – Shigonskiy, 12 – Stavropoljskiy, 13 – Krasnoyarskiy, 14 – Kinelcherkasskiy, 15 – Privolzhski, 16 – Bezenchukskiy, 17 – Volzhski, 18 – Kinel, 19 – Bogatovskiy, 20 – Borskiy, 21 – Khvorostyanskiy, 22 – Krashnoarmeyskiy, 23 – Neftegorskiy, 24 – Prstravskiy, 25 – Bolsheglushitskiy, 26 – Alekseyevskiy, 27 – Bolshochernigovskiy).

The highest degradation (4 points) was observed in Pokhvitnevskiy and Kamyshlinskiy districts, where intensive and destructive streams are formed on the slopes of Bugulma-Belebey Upland due to snowmelt and rains. Only 9% of the oblast land feature very high levels of degradation (4 points) and 29% of the land have high degradation levels (3 points). The farmlands with a medium degradation level (2 points) are the most prominent (36%). Low degradation level (1 point) was observed in 7 out of 27 districts (22% of the land area), and another 4 districts (4% of the land area) located mostly on the low-lying floodplain terraces of the Volga and the Samara have insignificant degradation (0 points). The fertility fall coefficient of the damaged land is 0.88–0.95 on average, and if we take into account the area of damages, it will be between 0.96 and almost 1.00.

Despite the arid climate of Samarskaya oblast, all of the districts feature damages due to the changes in the hydrological regime and the water-salt imbalance in soils. The area of such damages is insignificant and their degradation is rated at 0 points (insignificant). However, a comprehensive review of the respective processes (overwatering, waterlogging, and bogging, as well as salination and alkalization) helps identify districts with greater aggregate damages and 1-point degradation (Figure 2b).

Thus, the overwatering of soils in Samarskaya oblast due to seasonal or weather-related increase of water level in rivers (waterlogging), the reservoir regimes, and lateral seepage (flooding) can be observed in 3.1% of the farmland. Across the districts, this parameter varies between 0.4 and 8.7%. Normally, these are river flood plains and bottoms of enclosed hollows featuring steady dehumidification and acidification of soils. The largest damaged areas are found in the districts with large rivers (Samara, Bolshoy Kinel, Kondurcha, Sok, Bolshoy Cheremshan). The reservoirs in the chains of Saratov and Kuybyshev hydroelectric power plants and other waterworks also take up large areas. However, these areas have insignificant overwatering (fertility fall coefficient of 0.95 [17]).

In some very limited areas in Samarskaya oblast, the overwatering of undrained soils, as well as the appearance of perched water tables on overconsolidated soils, lead to bogging. The proportion of bogged farmlands is just 0.42%. The largest damaged areas can be found in the Bezenchukskiy district (3.8% of the land area), which is explained by the great expansion of the Volga during the flood season and the waterlogging of lower terraces. The majority of damaged lands belong to the medium-
bogged class (fertility fall coefficient of 0.75 [17]) and they can be used for hay harvesting. There are also areas of heavy and mild bogging (their coefficients are 0.37 and 0.85 respectively).

Salinated farmlands also take up very small proportions of the farmland in Samarskaya Oblast. Salt marshes are very rare, they mostly occur at the bottoms of river valleys or large coombes, where salinated ground waters discharge. In the majority of the districts, the proportions of salinated and alkalized soils are very small. The only exception is the Bolshechernigovskiy district, where 15.1% of the farmlands feature this type of damages (1-point degradation). The fertility fall coefficient varies greatly depending on the degree of soil salination: from 0.85 for the mild to 0.40 and 0.15 for medium and heavy salination [17].

Since the proportions of farmlands damaged due to the water-salt imbalance in soils are insignificant, the fertility fall coefficient values for the majority of the districts of Samarskaya oblast were close to 1.0 (from 0.98 to almost 1.00). Even the Bolshechernigovskiy district has a relatively high result: 0.97.

Another factor for fertility fall in Samarskaya oblast is stone clogging (1.85% of the farmland). This process is most prominent in the districts where soils are formed on the eluvium of hard rocks. These include Pokhvistnevskiy and Kamyshlinskiy districts (1-point degradation) (Figure 2c). However, this process is not very profound there as well: the fertility fall coefficient is 0.980, or 0.997-0.999 if we consider the land area.

The analysis of the data on the scale of soil disturbance due to adverse impacts showed that water erosion is the main cause of farmland degradation in Samarskaya Oblast. Its influence (26.6% of the farmland) is substantially stronger than that of other impacts (Figure 3). This pattern can be observed in almost all of the region’s districts. The only exception is the Privolzhskiy district where water erosion is mild and can be compared with other impacts (soil drifting, overwatering).

![Figure 3. Degradation levels for the farmland of Samarskaya oblast.](image)

Considering all of the above, the main goal of soil protection activities in almost all of the districts in Samarskaya oblast is mitigating soil erosion. Soils can be protected from erosion through organized measures. Field tracks, windbreaks, and other linear objects are located so that they will not accumulate the drainage. The field must be arranged to facilitate cross-slope tilling.

In rugged terrains, contour improvement arrangement of crop rotation lands receives great importance. In this case, the edges of crop rotation fields and worksites follow the horizontal bends of the terrain, so that furrows crossed the water stream at a right angle only. The contour improvement arrangement of territories is especially relevant for the north-eastern districts of the region, where arable lands feature slopes, hollows, coombs, and microdepressions.

The set of agrotechnical actions to protect arable lands from erosion depends on the steepness of slopes, soil removal, and other factors. The key actions include conservation tillage, snow capture, and
snow melting control. For example, moldboard or boardless tillage across the slope is recommended for slopes up to 3°. It is preferable still to work along the horizontals, use common plows or boardless tools, and till to the required depth. For the medium and highly eroded soils with a thin humus layer sloping up to 5°, it is recommended to use ridge-and-flap plowing and boardless tillage across the slope or along the horizontal. When tilling fields with 3-5° sloping, stepped different depth, ridge, or combined plowing is used, and the recommended ridge height is 20-30 cm. If the sloping is more than 5°, it is recommended to grass it down completely with perennial legume-grass mixtures. Heavy soils with bad water permeability used for fall plowing and winter crops require paraplowing to the depth of 40-50 cm in late autumn before the soil freezes.

Protective forest ranges play a crucial role in ensuring the water regime that is favorable for agriculture (especially in the steppe and dry steppe zones), mitigating droughts and dry hot winds and increasing the crop yields. They must form a system of different plant types and functions. They may include wind-break strips, gulch and slope forest belts, forest ranges around ponds and other water bodies, forest strips on irrigated territories, sands, and sandy soils, etc.

4. Conclusion

Thus, the assessment of soil degradation prioritizing the problems of environmentally-friendly land use and soil protection is a key stage in comprehensive land protection activities. The detailed classification of land resources and the spatial analysis of farmlands according to their natural properties create the information base for the environmental and economic evaluation of land protection activities, their prioritizing and justification across different districts. The zoning of farmlands according to their degradation driven by adverse impacts that are presented in this article forms a geographical basis for the land protection planning and land resource management in Samarskaya Oblast.

5. References

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