Geoinformation analysis of natural potential of agricultural lands in Samara region

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Abstract. The work was done in order to improve the territorial organization of agricultural production in the context of the implementation of the adaptive landscape land use strategy based on the assessment and analysis of the spatial and temporal structure of the natural agricultural potential (NAP) of the territory. The results of dynamic statistical simulation of normative crops productivity and land bonitet assessment of administrative districts of the Samara region are used. GIS analysis of the results and mesoscale comprehensive assessed zoning of the territory is applied. As a result, seven mesozones were allocated in the region with assurance accordance of the bonitet scales and crop productivity formation factors (correlation coefficients with many indicators 0.7-0.9), which include relevant assessment areas with the most uniform conditions (coefficient of variation of indicators within 10%). The zoning is done in the contours of the administrative division of the territory and forms the geographic basis for resolving the agro-production issues of the respective management and land assessment objects in the framework of the formation of the adaptive landscape land use system.

1. Introduction
The high rates of intensification of agricultural production that persisted in Russia in the second half of the 20th century, the lack of a scientifically based system of rational land use led to the emergence of land use contradictions related to both excessive anthropogenic pressure on the land in some cases, and underutilization of land resources in the others. This caused such problems as land desertification, land degradation, contributed to ravine formation and others, and thus predetermined the transition to a nature-oriented land use system based on adaptation to the existing conditions of the territory in recent decades.

In the works devoted to the issues of land use optimization, the need to ensure the efficient and sustainable use of agricultural resources in order to preserve soil fertility is noted [1-3]. At the same time, the rational organization of the cultivated land and the solution of production issues of farms’ specialization, the application of technologies for growing crops, and the organization of land reclamation should be carried out in accordance with the size and characteristics of the spatial distribution of the natural agricultural potential of the territory (NAP) [4, 5].

Many works of S.S. Sapozhnikova, D.I. Shashko, P.I. Koloskov and others are devoted to the issues of macro-scale (inter-regional) zoning of the climate, the allocation of natural agricultural belts and zones [6]. It is shown that at this level, it is the value of the bioclimatic potential of the territory (BCP) that determines the differentiation of agricultural production. In particular, it was established
that the territory of the Samara region is located within three natural zones – forest steppe, steppe, and dry steppe [7].

In [8–11], climate properties also underlie mesoscale zoning assessment of the territory. In accordance with the methodology [8], seven agroclimatic subzones were identified on the basis of physico-statistical modeling of the indicator of the agroecological potential of the territory in the Samara region [12]. However, the data obtained do not take into account soil fertility factors, which limits their use for practical purposes. This is due to the fact that, within the boundaries of natural zones, the dependence of crop productivity on climate influence is weakening due to various kinds of azonal factors, primarily the heterogeneity of the earth's surface. A comprehensive assessment of NAP is advisable.

Within the framework of natural agricultural zoning of the territory of Russia, districts that reflect the differentiation of landscape properties (parent rocks, climate, topography, hydrography) and soil regions are allocated. The results obtained for the Samara region to some extent reflect the patterns of spatial distribution of these factors [7, 13, 14], but they also have some inconsistencies, especially noticeable in the forest steppe zone.

In modern conditions, mathematical modeling of crop productivity is widely used, taking into account all available resources of the territory, the spatial and temporal variability of existing factors [15]. The method allows taking into account and reflecting not only the differentiation of the territory properties, but also the provision of crops. This approach is more informative for solving production problems and developing systems for supporting economic decisions [16, 17].

The aim of the work is to provide information support for issues of the territorial organization of agricultural production based on modeling the normative productivity of crops in the administrative regions of the Samara region. The main tasks include the assessment and geoinformation analysis of NAP, land appraisal and integrated zoning assessment of the territory.

2. Conditions and methods
To solve the problems of organizing adaptive landscape farming, the results of NAP analysis using GIS technologies [18], in particular, the assessment and valuation of land in the Samara region based on modeling normative (really possible) productivity of grain crops (winter and spring wheat, spring barley) are used in this paper. Considering that cereals occupy more than 60% of the cultivated area in the Samara region, as well as their wide distribution and growth throughout all seasons of the year (winter and spring), the analysis of their yield forms the basis for assessing agricultural land [4].

Since the normative yield is obtained on the basis of a simulation dynamic and statistical model of the production process of plants at nodes of a regular spatial grid with a step of 10 km in many year-old cases, the results provide “flexibility” in reflecting the spatial and temporal structure of factors and the availability of plants to them. Based on the analysis of the time series of the normative yield, an assessment of the territory and appraisal of the lands of administrative regions of the Samara region have been performed.

The mesoscale integrated zoning of the territory was carried out in two stages. First, the analysis was carried out by maximizing the correlation of land bonitet with a complex of indicators of soil and climatic resources of the territory, and the corresponding boundaries of the mesozones were determined. At the second stage, the conditions within the mesozones were examined for the similarity of indicators of favorable conditions for the supply of plants with climate and soil factors within regions, and for the differences between regions.

3. Results and their discussion
The geoinformation analysis of the results and their correspondence to the distribution of soils and climatic characteristics, the peculiarities of the landscape of the territory revealed the feasibility of identifying seven natural agricultural mesozones in the Samara region (Fig. 1a).
Fig. 1. Integrated mesoscale natural agricultural zoning of the Samara region.

Four of them are allocated within the boundaries of the forest steppe natural zone of the region, two - in the dry steppe zone, and the steppe zone is represented as a whole. Their position is consistent with the landscape features of the territory. The spatial correlation coefficients of the average normative yield in mesozones with many soil and climatic indices turned out to be higher than 0.7 (Table 1). The characteristics of the formed mesozones are given in table 2.

**Table 1.** Spatial correlation coefficients of land bonitet and soil-climatic indicators in estimated mesozones of the Samara region.

| Natural zone                  | Volumetric mass of the soil, g/cm³ | Humus content in the soil, % | Productive moisture in the soil (August), mm | Sum of air temperatures, °C | Sum of air humidity deficits, hPa | Precipitation quantities, mm |
|------------------------------|-----------------------------------|------------------------------|---------------------------------------------|-----------------------------|-------------------------------|-------------------------------|
|                              |                                   |                              |                                             | Sum of air above +10°C      | below -10°C                   | April-October | November-March |
| Forest steppe                | -0.66                             | 0.93                         | 0.90                                        | -0.97                       | -0.95                         | 0.70            | 0.98           |
| Steppe and dry steppe        | 0.76                              | 0.99                         | 0.93                                        | -0.98                       | 0.81                          | 0.77            | 0.75           |
| Region                       | 0.11                              | 0.94                         | 0.94                                        | -0.96                       | -0.14                         | 0.91            | 0.89           |
Table 2. The generalized characteristic of estimated mesozones of the Samara region.

| Natural zone | Mesozone | Standard grain yield, kg/ha | Humus content in the soil, % | Productive moisture in the soil (August), mm | Sum of air temperatures, °C | Precipitation quantities for April-October, mm |
|--------------|----------|-----------------------------|-----------------------------|---------------------------------------------|-----------------------------|-----------------------------------------------|
|              |          |                             |                             |                                             | above +10°C | below –10°C |                                             |
| Forest steppe| 1        | 25.4                        | 5.5                         | 111                                         | 2229         | 1153       | 329                                           |
|              | 2        | 24.7                        | 6.0                         | 108                                         | 2167         | 1200       | 317                                           |
|              | 3        | 21.6                        | 4.7                         | 100                                         | 2350         | 1010       | 325                                           |
|              | 4        | 19.3                        | 3.7                         | 75                                          | 2400         | 1001       | 300                                           |
| Steppe       | 5        | 19.3                        | 4.1                         | 85                                          | 2460         | 1126       | 320                                           |
| Dry steppe   | 6        | 15.8                        | 3.6                         | 50                                          | 2500         | 1137       | 275                                           |
|              | 7        | 11.3                        | 2.8                         | 50                                          | 2600         | 1125       | 250                                           |

Considering the significant dispersion of indicators in the estimated mesozones, their additional division into regions was performed (Fig. 1b), in which the conditions are more uniform. For the analysis, we used the coefficients of favorable climate and soil conditions obtained by identifying the ratio of the normative yield calculated in optimal conditions and really possible.

It was established that in the steppe zone, the greatest variability of the normative yield and bonitet is ensured by a complex of soil and climatic conditions (Table 3), and the distribution of the product of climate and soil favorable factors is the basis for the allocation of regions.

As a result, the conditions of the steppe natural zone are presented in the form of four regions approximately corresponding to the ancient Volga river valley, the interfluve of the Samara and Bolshoy Kinel rivers, and two regions of the steppe Transvolga region - with a flat relief in the central part of the Samara region and gently rugged (wavy) on the spurs of Obtchei (common) Syrt in the southeastern part of the region.

Table 3. Generalized characteristic of the estimated areas of the Samara region.

| Natural zone | Mesozone, region | Land bonitet, score | Coefficient of favorable conditions, dimensionless |
|--------------|------------------|---------------------|-----------------------------------------------|
|              |                  |                     | Kk * Kp | Kk / Kp |
| Forest steppe| 1a               | 71                  | 0.35    | 0.52    |
|              | 1b               | 81                  | 0.39    | 0.53    |
|              | 2                | 76                  | 0.36    | 0.61    |
|              | 3                | 64                  | 0.29    | 0.98    |
|              | 4                | 59                  | 0.29    | 0.79    |
| Steppe       | 5a               | 51                  | 0.26    | 0.83    |
|              | 5b               | 64                  | 0.31    | 0.71    |
|              | 5c               | 60                  | 0.29    | 0.78    |
|              | 5d               | 53                  | 0.26    | 0.71    |
| Dry steppe   | 6                | 46                  | 0.23    | 0.65    |
|              | 7                | 32                  | 0.16    | 0.76    |

In the forest steppe zone, conditions are generally more favorable, and the variability of this indicator is less pronounced. The division into regions was carried out on the basis of the ratio of the favorable coefficients of climate and soil conditions with the provision of its variation coefficient within 10%. The conditions of the first mesozone (corresponding to the slopes of the Bugulmino-Belebeyevskaya Upland) are divided into two regions - the northeastern one with the highest elevations and deep rugged terrain, and to the south - the region with lower elevations and relatively leveled relief.
The obtained zoning results, in contrast to the previously proposed ones, reflect the mesoscale features of the spatial distribution of the soil cover and climatic factors in the complex, taking into account the supply of plants with environmental factors during the growing season. The use of physically justified methods of modeling the production process of plants, providing “flexibility” of reflecting the spatial and temporal distribution of factors, and also good compliance of the results with actual conditions confirm their reliability. This justifies the use of the completed mesozonation of the territory as a necessary geographical basis for solving issues of agricultural production within the framework of the formation of a system of adaptive landscape land use.

4. Practical significance
An adaptive landscape approach to the organization of land use is based on the use or creation of a set of conditions that most satisfy the biological needs of crops by optimization of technologies and rational organization of territories. For this purpose, as is known, the analysis and identification of elementary agroecological areas of the landscape is carried out, which are typified and grouped.

When creating a farming system, the solution of individual tasks is carried out at different levels. In particular, for groups of landscapes corresponding in scale to natural agricultural zones and provinces, the issues of creating large reclamation systems and the development of general schemes for anti-erosion measures are being addressed. The most detailed conditions are considered when solving organizational issues for individual farms. Taking into account the microclimatic features of the elements of the cultivated lands, rational crop rotation, adapted varieties and technologies are used, which ensures improved soil fertility, increased land productivity and ecological safety of cultivated lands.

The development of crop rotation, reclamation and anti-erosion measures, the definition of the structure of sown areas, and the formation of crop cultivation technology are carried out for different types of cultivated lands. Mesozones identified in this work correspond to the types of natural landscape, reflect the soil and climatic conditions for the formation of productivity, and represent a geographical basis for solving issues of land use design, production planning, and land assessment.

5. Conclusion
Thus, the obtained results of the territory zoning, in contrast to the previously proposed ones, reflect mesoscale features of the spatial distribution of soil cover and climatic factors in the complex, taking into account the supply of plants with environmental factors during the growing season.

The advantages of the dynamic and statistical simulation technique of the production process are provided with the ability to analyze the properties of the territory at the mesoscale level. The obtained distributions of the normative yield of grain crops and agricultural land bonitet are not distorted by the influence of the agrotechnical factor, and, unlike other options, more accurately and completely reflect the natural and economic properties of the territory in the land-estimated regions of the Samara region. The physical validity and environmental nature of the simulation results provide the basis for their practical use.

Zoning is carried out in the contours of the administrative division of the territory and thereby forms the information basis for resolving agro-industrial issues and organizing land use of the respective management and land assessment objects.

Acknowledgements
This study was carried out as part of the research work “Meteorological justification of agricultural technologies and agricultural design” (registration in the Unified State R&D Statistics Information System No. 116041210128).

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