**Sergey S. Ogorodnikov**[1] **DOI: 10.35595/2414-9179-2025-2-31-489-496**

# GEOSPATIAL ASSESSMENT OF SOIL NUTRIENT AVAILABILITY FOR SUSTAINABLE LAND MANAGEMENT: A CASE STUDY OF THE DON RIVER BASIN

## ABSTRACT

This study presents a geospatial approach to the assessment of soil fertility within a representative agricultural territory in the Don River Basin. The analysis is based on the integration of agrochemical survey data with cartographic modeling using GIS tools, enabling the construction of detailed maps for key soil properties, including humus content, soil pH, nitrogen (N), phosphorus (P), and potassium (K) availability. The results demonstrate a high degree of spatial heterogeneity in nutrient distribution across the study area. Medium-humus chernozems predominate, while high-humus zones in the western sector exhibit lower pH values, indicating enhanced acidity due to the presence of humic acids and reduced calcium buffering. Nitrogen availability shows a patchwork pattern, with medium and high content dominating, although low-nitrogen zones persist in the western part of the region. Phosphorus availability is markedly elevated in the central part of the area, suggesting potential over-application of fertilizers and ecological oversaturation. Potassium, in contrast, is uniformly abundant, indicating non-limiting status for crop production. An integrated fertility index was developed by overlaying the individual nutrient maps, revealing that 20.3 % of the territory represents high-fertility reference soils, while 15.8 % requires fertility enhancement. The findings confirm the utility of geoinformation methods in agrochemical monitoring and support their application for sustainable land-use planning and adaptive management of soil resources. The methodology offers a replicable framework for regional agroecological diagnostics.

**KEYWORDS:** soil fertility, GIS analysis, humus content, nutrient mapping, sustainable land management, Don River Basin

## INTRODUCTION

The effective management of agricultural landscapes under conditions of increasing environmental constraints necessitates a detailed understanding of soil fertility patterns and their spatial heterogeneity [*Usman*, 2025]. As soil nutrient status directly governs plant productivity, biogeochemical cycling, and ecological sustainability [*Dan*, 2024], precise diagnostics of agro-chemical parameters has become a cornerstone in the development of adaptive land-use strategies. In particular, spatially explicit assessments of humus content, soil pH, and the availability of key macronutrients — nitrogen (N), phosphorus (P), and potassium (K) — represent indispensable tools for optimizing agro-ecological zoning and minimizing resource misallocation in contemporary agricultural systems [*Petito*, 2024].

Traditional soil monitoring practices, although analytically robust, often lack spatial representativeness and fail to capture intra-field variability critical for precision agriculture and environmental risk assessment [*Gerth*, 2017]. In this regard, the integration of Geographic Information Systems (GIS) with agrochemical survey data provides a methodological advantage [*Greene*, 2015], allowing for the generation of detailed soil fertility maps, identification of high- and low-productivity zones, and formulation of site-specific management recommendations.

[1] Moscow Aviation Institute (National Research University), Faculty 614, 4, Volokolamskoe hwy., Moscow, 125993, Russia, *e-mail:* **sir.ogorod@yandex.ru**

Within the context of Central Russia's chernozem landscapes — renowned for their high agronomic potential yet susceptible to degradation from unbalanced nutrient management — the application of GIS-based soil diagnostics holds particular relevance. The Don River Basin, encompassing historically cultivated lands such as the former state farm "Tikhiy Don" presents a representative case of diversified soil fertility, shaped by both natural pedogenesis and anthropogenic inputs [*Uwamahoro*, 2024]. Despite its agricultural significance, this territory lacks systematic spatial fertility characterization essential for evidence-based decision-making and sustainable development planning [*Prăvălie*, 2021].

This study aims to fill that gap by conducting a comprehensive geospatial analysis of agrochemical indicators across the study area, thereby:

1. Mapping the distribution of humus, pH, N, P, and K levels.
2. Identifying reference soils with optimal nutrient supply.
3. Deriving an integrated soil fertility index.

Through this approach, we demonstrate the applicability of geoinformation technologies in revealing latent patterns of soil resource distribution and informing regional policies for rational land use, food security, and ecological resilience [*Stockmann*, 2020].

## RESEARCH MATERIALS AND METHODS

The study area is located within the Don River Basin and corresponds to the agricultural territory of the former state farm "Tikhiy Don" in the central part of the Russian steppe zone. This region is characterized by fertile chernozem soils, temperate continental climate, and historically intensive agricultural use. To evaluate the spatial distribution of soil agrochemical properties, a comprehensive field survey and laboratory analysis were conducted, followed by geostatistical processing within a GIS environment [*Lebedev*, 2024].

The agrochemical survey was performed in accordance with national soil monitoring standards and included the collection of representative soil samples at multiple depths across the territory. The sampling points included sites both within cultivated fields and in proximity to rural settlements. These locations were historically part of the state farm "Tikhiy Don" agro-landscape, where residential boundaries often intersected with productive agricultural parcels. Therefore, the selection reflects legacy land use patterns and ensures the representation of all major agroecological units within the study area.

In total, 42 sampling points were established across the study area, with composite samples taken from the 0–20 cm horizon at each site. Each sample was analyzed in triplicate to ensure analytical reliability. The spatial dataset thus comprises 126 agrochemical measurements for each parameter. Statistical interpolation and thematic classification were based on the resulting georeferenced dataset using kriging methods with cross-validation in the QGIS 3.16 environment.

Laboratory analyses determined the concentrations of the following key fertility indicators:

- **humus content (%)** assessed via the Tyurin method [*Kellogg*, 2010];
- **soil reaction (pH in KCl)** measured potentiometrically;
- **total nitrogen (%)** determined using the Kjeldahl method;
- **available phosphorus (mg/kg)** extracted with 1 % citric acid and measured colorimetrically;
- **exchangeable potassium (mg/kg)** extracted with ammonium acetate and quantified by flame photometry.

Geospatial data processing was carried out using the QGIS platform (version 3.16), which enabled the interpolation and cartographic visualization of agrochemical parameters across the study area [*Wang*, 2023]. Each soil property was analyzed individually through thematic mapping, allowing the delineation of spatial patterns and identification of zones with contrasting fertility levels. The resulting maps include:

- humus content distribution;
- soil pH distribution;
- nitrogen availability;
- phosphorus availability;
- potassium availability.

To synthesize these individual indicators into a comprehensive assessment, an **Integrated Soil Fertility Index (ISFI)** was computed by overlaying the classified thematic layers. The ISFI was categorized into five fertility classes based on expert-defined thresholds, enabling the identification of reference soils-zones exhibiting consistently high levels of all essential nutrients.

This methodological framework ensures both analytical rigor and spatial resolution, providing a replicable model for regional-scale soil diagnostics and land-use optimization [*Flint*, 2024].

**RESEARCH RESULTS AND DISCUSSION**

The spatial distribution of humus content reveals a predominance of medium-humus chernozems (5–7 %) throughout the study area. High-humus soils (7–9 %) are localized in the western segment [*Petito*, 2024], forming a distinct areal cluster with elevated organic matter reserves. In contrast, low-humus zones occupy marginal areas and are of limited extent [*Chikaraishi*, 2017].

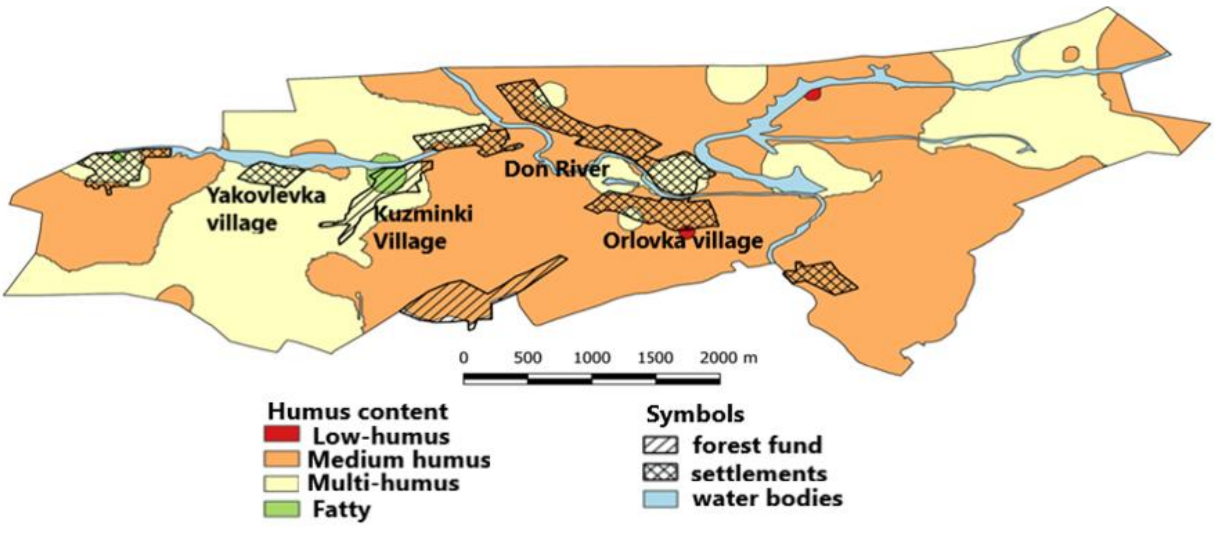


*Fig. 1. Humus content distribution map*

The pH distribution map shows that over half of the study area (51 %) is characterized by weakly acidic to neutral conditions (pH > 6.0), which are generally favorable for crop growth [*Gerth*, 2017]. However, zones with elevated humus levels in the western and northeastern sectors display notably lower pH values (4.6–5.5).

The nitrogen supply across the territory exhibits pronounced heterogeneity. Medium (25 %) and high (21 %) nitrogen availability dominate, forming a mosaic structure. Notably, the lowest nitrogen concentrations are observed in the western regions [*Dan*, 2024], while nitrogen-rich soils are concentrated near the Don floodplain [*Ma*, 2023].

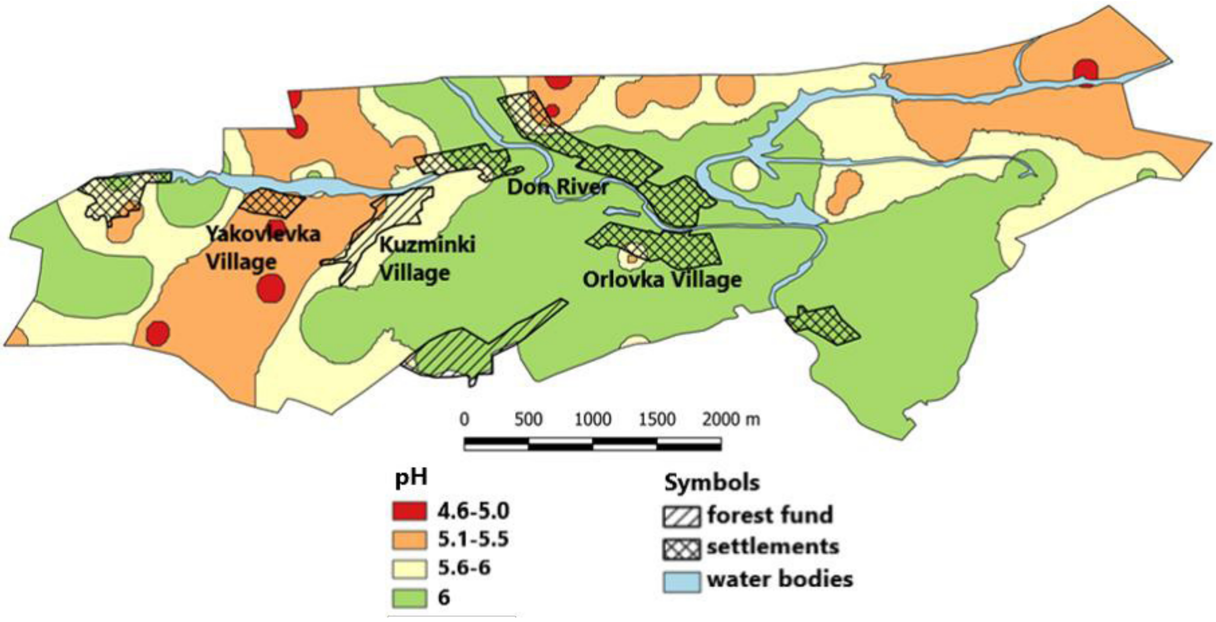


*Fig. 2. Soil pH distribution map*

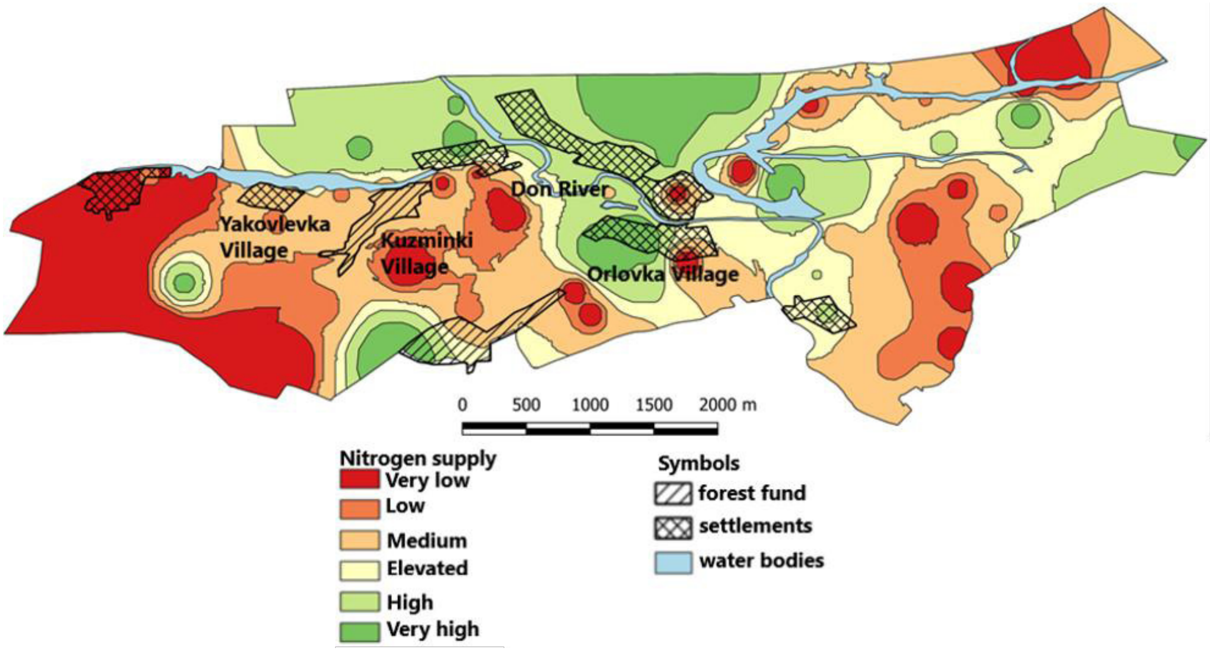


*Fig. 3. Nitrogen availability map*

Phosphorus distribution is marked by elevated concentrations in the central part of the study area, where 42 % of the land shows high and 18 % very high levels of available forms. Only 2–3 % of the area falls into low phosphorus categories [*Oswald*, 2023].

The territory demonstrates a consistently high potassium status. According to the cartographic analysis, 32 % of the area exhibits very high potassium content, 42 % high, and 24 % moderately elevated levels [*Yin*, 2022].

By overlaying the individual fertility maps, an Integrated Soil Fertility Index was constructed. The results show that 63.9 % of the study area falls into the medium fertility class, while 20.3 % qualifies as high-fertility reference soils-zones suitable for intensive agricultural

[*Yasarer*, 2016; *Wang*, 2023] use with minimal additional inputs. Conversely, 15.8 % of the land exhibits low nutrient availability, requiring corrective agronomic measures.

The distribution of soil fertility scores confirms the predominance of moderately fertile soils, while more than 10 % of the territory displays optimal fertility conditions (scores of 16–20), which makes them particularly suitable for high-value crops or conservation agriculture initiatives [*Kellogg*, 2010].

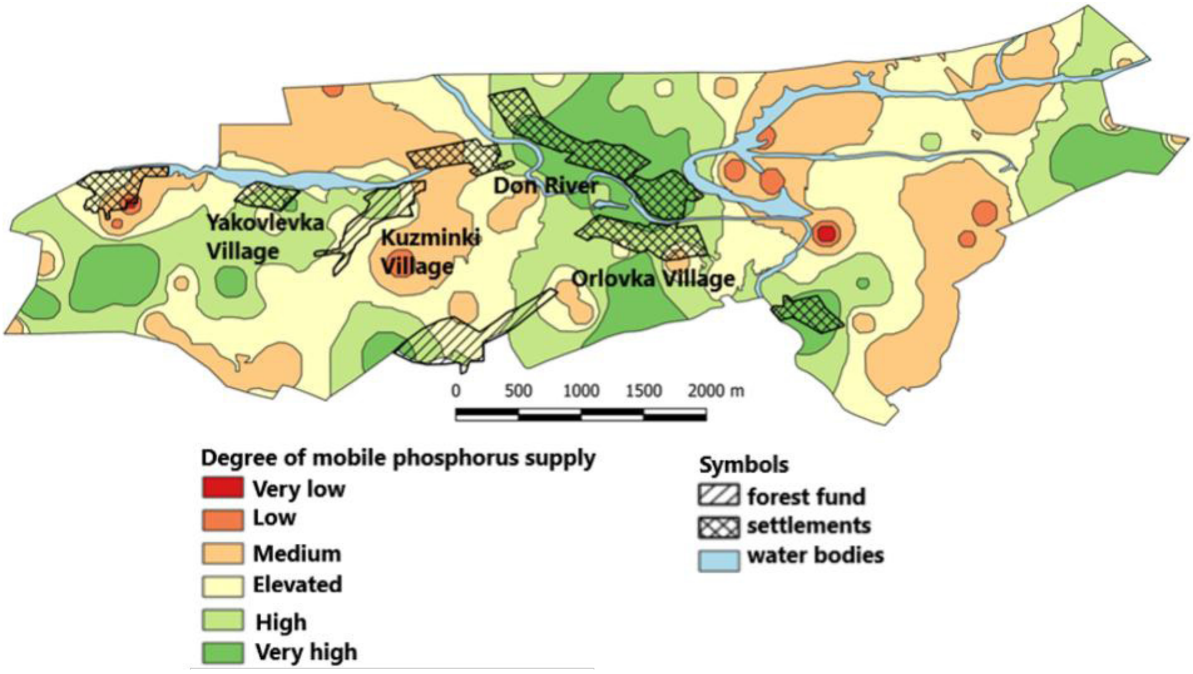


*Fig. 4. Available phosphorus distribution map*

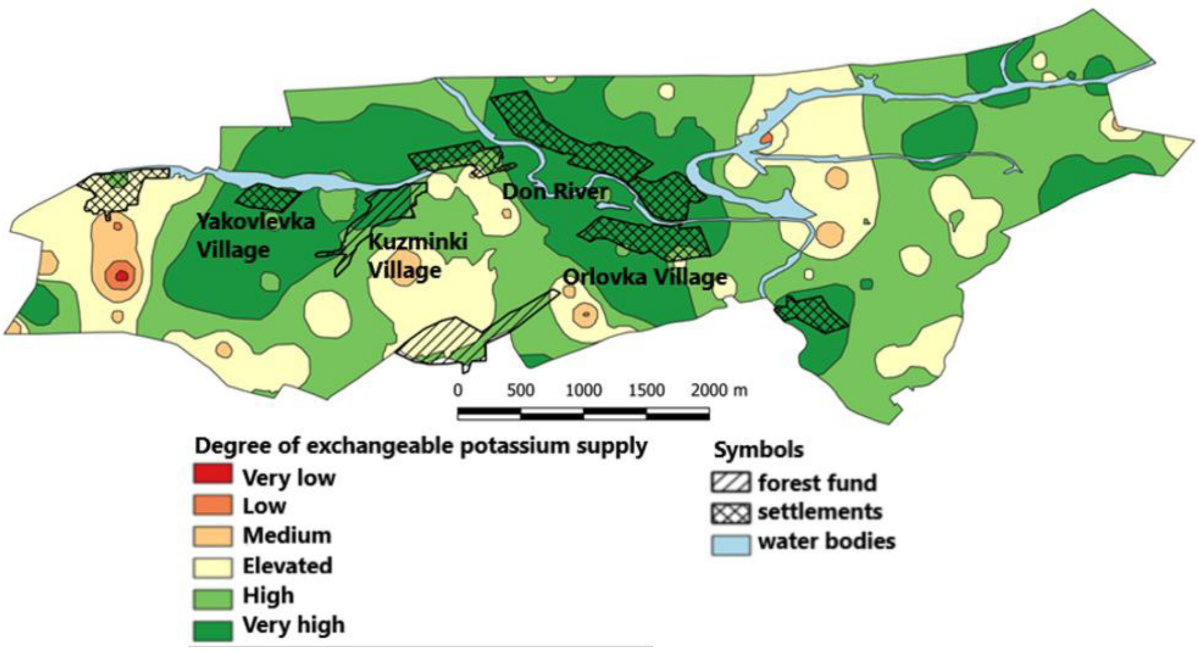


*Fig. 5. Exchangeable potassium map*

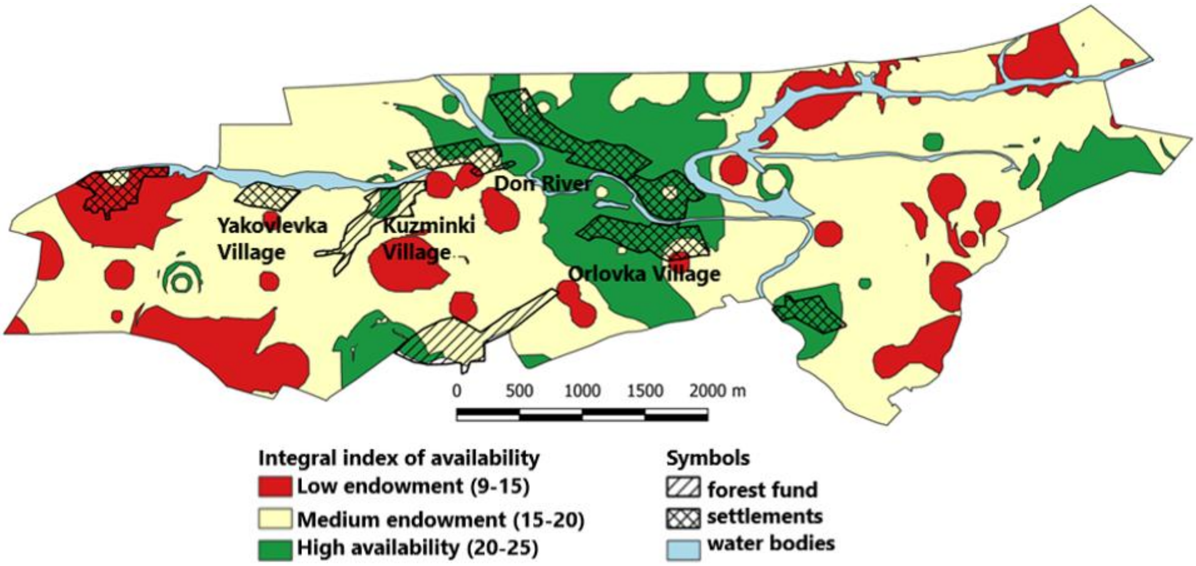


*Fig. 6. Integrated soil fertility index map*

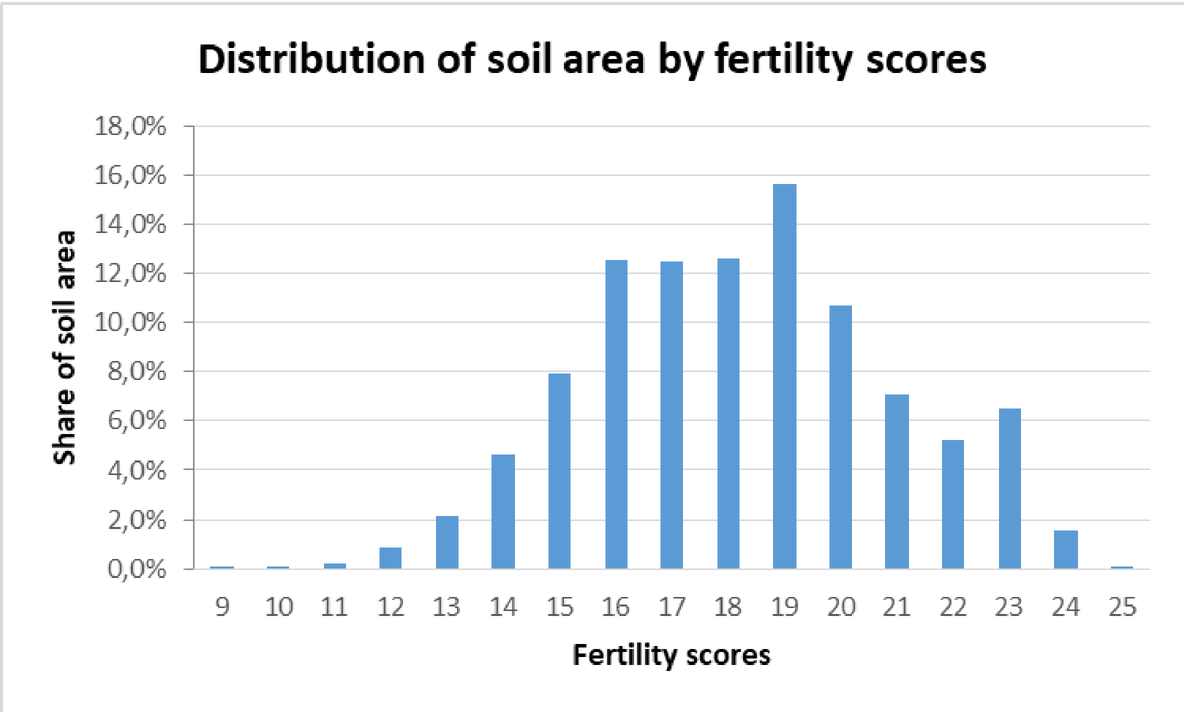


*Fig. 7. Fertility class distribution diagram*

## CONCLUSIONS

This study demonstrates the efficacy of geoinformation approaches in diagnosing and visualizing the spatial heterogeneity of soil nutrient availability [*Greene*, 2015] within an agriculturally significant landscape of the Don River Basin. By integrating laboratory-based agrochemical data with GIS-based spatial analysis, we established a comprehensive methodology for identifying zones of high agronomic potential and nutrient deficiency [*Chikaraishi*, 2017].

Key findings include:

1. The predominance of medium-humus chernozems (5–7 %) and the spatial confinement of high-humus soils (7–9 %) to the western sector of the study area.
2. A notable inverse relationship between humus content and soil pH, attributed to the acidifying effect of humic substances, which necessitates localized pH correction measures [*Metechko*, 2018].
3. Significant spatial variability in nitrogen availability, with both deficient and enriched zones identified, particularly along the Don floodplain.
4. Evidence of phosphorus accumulation in the central territory, potentially indicating over-fertilization and heightened risk of agroecological oversaturation.
5. Stable and uniformly high levels of exchangeable potassium, suggesting non-limiting conditions for this nutrient.
6. The delineation of reference soils (20.3 % of the area) with consistently high nutrient availability, suitable for model agricultural use.
7. The successful application of the Integrated Soil Fertility Index (ISFI), offering a spatially explicit framework for agroecological classification and targeted land management interventions.

These results provide a scientifically grounded basis for optimizing fertilizer use, implementing precision agriculture technologies, and supporting the sustainable development of socio-natural systems. Moreover, the methodological framework presented herein may be adapted for use in other regions with similar edaphic and agroclimatic conditions, contributing to the broader agenda of sustainable land resource management.

## REFERENCES

*Chikaraishi Y., Ohkouchi N., Close H. G., Fry B., Larsen T., Madigan D. J., McCarthy M. D., McMahon K. W., Nagata T., Naito Y. I., Ogawa N. O., Popp B. N., Steffan S. A., Takano Y., Tayasu I., Wyatt A. S. J., Yamaguchi Y. T., Yokoyama Y.* Advances in the Application of Amino Acid Nitrogen Isotopic Analysis in Ecological and Biogeochemical Studies. Organic Geochemistry, 2017. V. 113. P. 150–174. DOI: 10.1016/j.orggeochem.2017.07.009.

*Dan S. F., Zeng X., Tang J.* Dissolved N Pollution and its Biogeochemical Constraints Along a River-Sea Continuum of a Typical Dense Oyster Mariculture Coastal Water, Northwest South China Sea. Journal of Hazardous Materials, 2024. V. 480. Art. 136207. DOI: 10.1016/j.jhazmat.2024.136207.

*Flint C. G., Henderson L. A., Hensley M. V.* Chapter 17 — Fostering Interactional Resilience in Social-Ecological Riverine Landscapes: A Case Study from the Santa Fe River Watershed in New Mexico, US. Resilience and Riverine Landscapes, 2024. P. 341–362. DOI: 10.1016/B978-0-323-91716-2.00007-8.

*Gerth W. J., Li J., Giannico G. R.* Agricultural Land Use and Macroinvertebrate Assemblages in Lowland Temporary Streams of the Willamette Valley, Oregon, USA. Agriculture, Ecosystems & Environment, 2017. V. 236. P. 154–165. DOI: 10.1016/j.agee.2016.11.010.

*Greene S., Johnes P. J., Bloomfield J. P., Reaney S. M., Lawley R., Elkhatib Y., Freer J., Odoni N., Macleod C. J. A., Percy B.* A Geospatial Framework to Support Integrated Biogeochemical Modelling in the United Kingdom. Environmental Modelling & Software, 2015. V. 68. P. 219–232. DOI: 10.1016/j.envsoft.2015.02.012.

*Kellogg D. Q., Gold A. J., Cox S., Addy K., August P. V.* A Geospatial Approach for Assessing Denitrification Sinks within Lower-Order Catchments. Ecological Engineering, 2010. V. 36. Iss. 11. P. 1596–1606. DOI: 10.1016/j.ecoleng.2010.02.006.

*Lebedev I. I.* Machine Learning for Chemical-Humus Correlation in Soil. BIO Web of Conferences, 2024. V. 113. Art. 04008.

*Ma Z., Guan K., Peng B., Sivapalan M., Li L., Pan M., Zhou W., Warner R., Zhang J.* Agricultural Nitrate Export Patterns Shaped by Crop Rotation and Tile Drainage. Water Research, 2023. V. 229. Art. 119468. DOI: 10.1016/j.watres.2022.119468.

*Metechko L. B., Sorokin A. E.* Cluster Strategy for Eco-Innovation at Manufacturing Enterprises. Russian Engineering Research, 2018. V. 38. No. 4. P. 316–319.

*Oswald C. J., Kelleher C., Ledford S. H., Hopkins K. G., Sytsma A., Tetzlaff D., Toran L., Voter C.* Integrating Urban Water Fluxes and Moving Beyond Impervious Surface Cover: A Review. Journal of Hydrology, 2023. V. 618. Art. 129188. DOI: 10.1016/j.jhydrol.2023.129188.

*Petito M., Cantalamessa S., Pagnani G., Pisante M.* Modelling and Mapping Soil Organic Carbon in Annual Cropland under Different Farm Management Systems in the Apulia Region of Southern Italy. Soil and Tillage Research, 2024. V. 235. Art. 105916. DOI: 10.1016/j.still.2023.105916.

*Prăvălie R.* Exploring the Multiple Land Degradation Pathways Across the Planet. Earth-Science Reviews, 2021. V. 220. Art. 103689. DOI: 10.1016/j.earscirev.2021.103689.

*Stockmann U., Kidd D., Searle R., Grundy M., McBratney A., Robinson N., O'Brien L., Zund P., Arrouays D., Thomas M., Padarian J., Jones E., McLean Bennett J., Minasny B. B., Holmes K., Malone B. P., Liddicoat C., Meier E. A., Wilson P., Wilford J., Triantafilis J.* Operationalising Digital Soil Mapping — Lessons from Australia. Geoderma Regional, 2020. V. 23. Art. e00335. DOI: 10.1016/j.geodrs.2020.e00335.

*Usman S.* Advanced Soil Conservation for African Drylands: From Erosion Models to Management Theories. Pedosphere, 2025. In Press, Journal Pre-proof. DOI: 10.1016/j.pedsph.2025.01.012.

*Uwamahoro S., Liu T., Nzabarinda V., Frankl A., Tuyishimire E., Iradukunda A., Ingabire R., Umugwaneza A.* Investigation of Groundwater-Surface Water Interaction and Land Use and Land Cover Change in the Catchments: A Case of Kivu Lake, DRC-Rwanda. Groundwater for Sustainable Development, 2024. V. 26. Art. 101236. DOI: 10.1016/j.gsd.2024.101236.

*Wang G., Peng W., Zhang L., Zhang J.* Quantifying the Impacts of Natural and Human Factors on Changes in NPP Using an Optimal Parameters-Based Geographical Detector. Ecological Indicators, 2023. V. 155. Art. 111018. DOI: 10.1016/j.ecolind.2023.111018.

*Yasarer L. M. W., Sinnathamby S., Sturm B. S. M.* Impacts of Biofuel-Based Land-Use Change on Water Quality and Sustainability in a Kansas Watershed. Agricultural Water Management, 2016. V. 175. P. 4–14. DOI: 10.1016/j.agwat.2016.05.002.

*Yin L., Wei Z., Shi H., Ding D.* Ecosystem Services Assessment and Sensitivity Analysis Based on ANN Model and Spatial Data: A Case Study in Miaodao Archipelago. Ecological Indicators, 2022. V. 135. Art. 108511. DOI: 10.1016/j.ecolind.2021.108511.