Multi-scale soil-landscape maps as the basis of geographic information systems for soil melioration

A A Nikiforova1*, M E Fleis2 and N N Kazantsev2

1 Faculty of Soil Science, Lomonosov Moscow State University, GSP-1, Leninskie Gory, Moscow 119991, Russian Federation
2 GIS Research Laboratory, Institute of Geography, RAS, 29 Staromonetniy pereulok, Moscow 119017, Russian Federation

*E-mail: nikifsoil@gmail.com

Abstract. The necessity of creating multi-scale soil-landscape maps for making scientifically based decisions on soil melioration at all levels is substantiated. Multi-scale soil-landscape maps are called a system of interrelated maps of all scale ranges, obtaining automatically from expert integral polygonal layers, having a single classification basis, containing integrated information about soils and landscapes and displaying soils not only as independent natural bodies (that is, systems) but also as derived elements of landscape systems. The ways of integrating heterogeneous information about soils and landscapes contained in cartographic and textual sources are named. The concept of “global data integration” is revealed and the importance of its implementation in relation to the soil and landscapes is emphasized. The advantages of multi-scale soil-landscape maps are shown in comparison with traditional and modern digital soil maps, which are due to the use of the genetic hierarchical Soil-Landscape Classification System as the classification basis.

1. Introduction
To create a scientifically based hierarchical decision-making system on soil melioration at all levels (from global to local), integrated information is needed not only on soils, but also on all soil forming factors, which has a unified cartographic basis. As such a basis, it is proposed to use multi-scale soil-landscape maps created in the environment of geographic information systems (GIS). Traditional and modern digital soil, landscape and other thematic maps are neither individually nor collectively unsuitable for this. The fact is that they were created and continue to be created at different scale ranges (or scales), in different coordinate systems, using different theoretical concepts and different geographical and classification bases. As a result, they contain heterogeneous, insufficient, often inconsistent and contradictory information.

2. The problem of global integration of spatial data on soils and soil forming factors

2.1. Types of integration of spatial data on soils and soil forming factors
Integration of spatial data on soils and soil forming factors is a fundamental problem of soil science. However, of all types of integration, only spatial, geographical and horizontal integration is currently being implemented. By spatial integration, we mean the conversion of spatial data to the basic coordinate system, by geographical - the linkage of spatial data to a single geographical basis, and by
horizontal – the integration of the thematic content of spatial data at a single scale range (or at a single scale). The horizontal integration of spatial data on soils and soil forming factors is currently carried out in the following ways: (1) by creating a universal (unified, basic) soil classification system [1]; (2) by creating a global (world) soil map (GlobalSoilMap.net project) regardless of creating of a universal soil classification system; (3) by creating maps of soil classes and properties using modern technologies, mathematical and statistical pedometric methods and numerical (quantitative) classification systems [2-4] and (4) by overlay operations in a GIS environment [5]. Simultaneously, undeservedly little attention is paid to other types of integration. These include:

- Thematic integration, that is, the integration of thematic content of spatial data on the basis of a universal classification system [6].
- Vertical integration, that is, the integration of thematic content of spatial data of all scale ranges.
- Temporal integration, that is, the integration of spatial data on objects that change over time as a result of evolution, changes in environmental conditions or the impact of anthropogenic factors on them.

All these types of integration, implemented jointly, mean global (comprehensive) integration.

2.2. The ways to solve the problem of global integration of spatial data on soils and soil forming factors

As our experience shows, the problem of global integration of spatial data on soils and soil forming factors can be solved by using: (1) the systems approach, which consists in consideration objects as systems and system elements [7], (2) contemporary theories of classification [8-10] and (3) fundamental concepts of soil science and landscape sciences and, above all, definition of soils given by Dokuchaev [11, 12]. However, attempts to apply the systems approach in soil science and landscape sciences today are few, not fully implemented and, therefore, not very successful [13-15]. Contemporary theories of classification are largely ignored when developing soil classification systems, and the definition of soils given by Dokuchaev is usually partially used, that is, only its first part is taken into account (namely, the soil is a natural body), and the second, no less important, (the soil is the result of interaction of soil forming factors) is basically only announced [16]. Therefore, the existing soil classification systems and maps based on them reflect soils, mainly as independent natural objects, and not as a result of the interaction of soil forming factors.

3. Multi-scale soil-landscape maps

3.1. The concept of multi-scale soil-landscape maps

By multi-scale soil-landscape maps we mean a system of interrelated maps of all scale ranges, having a single classification basis, containing integrated (that is, structured, consistent, forming a unified system) information about soils and landscapes and displaying soils as independent natural bodies (that is, systems) and as derived elements of landscape systems [17]. These maps greatly facilitate analysis of conditions of soil formation, make it possible to identify soil-landscape relationships and patterns of the geographical distribution of soils and landscapes, as well as to predict changes in soil and other landscape elements properties. Examples of multi-scale soil-landscape maps are maps: types of vertical landscape structure, sets of landscape elements (presence/absence of soils), landscape elements properties (the latter include maps of types of megarelief, zonal types of vegetation, properties of soils, which are formed under zonal types of vegetation, texture of parent materials, texture of soils formed from various parent materials, chemical composition of groundwater, soil salinization, etc.).

The classification basis for multi-scale soil-landscape maps is the genetic hierarchical Soil-Landscape Classification System developed by the authors using contemporary theories of classification, which represents a complete hierarchy, combines a soil classification system and a landscape classification system and can serve as the basis for a classification system of anthropogenic soils and landscapes [18, 19]. The objects of the classification are natural soils and natural landscapes.
From the position of the systems approach, we call: (1) natural landscapes - material systems consisting of interacting and interconnected natural elements (basic - rocks, water, air, living and dead organisms, and derived - soils), (2) natural landscape elements - minimal structural units of natural landscape systems, represented by material substances with homogeneous properties, and (3) natural soils - derived landscape elements, which are formed because of the interaction of the basic landscape elements, and simultaneously independent material systems.

3.2. Creating multi-scale soil-landscape maps

Multi-scale soil-landscape maps are created using GIS technologies based on mainly expert analysis of existing thematic maps containing information about soils and basic landscape elements and their properties, as well as using Earth remote sensing data, digital elevation models, laboratory results, and meteorological, field and literary data. This information includes data on the macro-, meso- and microclimate; precipitation, air and soil temperature, relative air humidity, evaporation from the soil surface; mega-, macro-, meso- and micrelief forms and their elements; surface slopes, slope exposure, natural drainage of plots; geological structure of the area, the lithological composition of parent materials and bedding rocks; depth, salinity and intensity of additional groundwater recharge; water availability of the area, the presence and characteristics of reservoirs, rivers, lakes, ponds; zonal types of vegetation; thickness, texture, water capacity, water permeability, capillary conductivity of soil horizons; capillary elevation, degree and type of salinization of soils, water-salt regime and nutrient content of soils, susceptibility of soils to erosion and so on.

GIS mapping is a natural continuation of traditional mapping, but at a higher qualitatively new technological level. Thanks to GIS, many of the disadvantages of traditional soil maps can be eliminated, for example, their content can be significantly increased [20,21]. This is due, among other things, to the fact that the basic principles of GIS are to provide a link between coordinate (cartographic) and attribute (textual, descriptive) spatial data and their layered display. In addition, GIS allows you to work with an almost unlimited amount of spatial data, namely, to accumulate, coordinate, formalize, structure and integrate these data. Basher [22] expressed the following opinion about the importance of integrating information gathered at various scales using GIS: “Perhaps one of the greatest challenges will be to integrate information collected at different scales […] into GIS and soil information systems.” In turn, we consider GIS as a tool for the global integration of spatial data on soils and soil-forming factors (or, if you follow the terminology of the systems approach, soils, basic landscape elements and their properties).

Multi-scale soil-landscape maps are obtained automatically from integral polygonal layers (figure 1), created based on expert analysis of the largest possible amount of available information on soils.

Figure 1. Examples of multi-scale soil-landscape maps of the Saratov region, Russian Federation, generated in GIS from a single polygonal layer at scale range 1: 1,000,000 - 1: 2,500,000 (left to right and top to bottom): Genetic types of parent rocks, Soil texture, Surface roughness, River terraces, Zonal types of vegetation, Genetic soil types, Interstream areas and river valleys, Genetic types of macrorelief.
and landscapes for each scale range, contain integrated information about soils and landscapes, including properties of basic landscape elements, and are connected with each other. Information about the possibilities of using and improving soils and landscapes, corresponding to the various scale levels of the decision-making system, which allows obtaining the corresponding maps, can also be included into integral layers. Creation of maps was tested on the example of the plains of the European part of Russia [17, 23].

3.3. Content of multi-scale soil-landscape maps
Multi-scale soil-landscape maps are very high informative, as illustrated in table 1.

Table 1. The part of the attribute information contained in one of the polygons of the integral layer at scale range 1:500,000 - 1:1,500,000.

| Differentiating criteria                                                                 | Names and diagnostic criteria of natural landscapes and soils                                                              |
|----------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|
| Stability/instability of vertical structure of landscapes                               | **Landscapes with stable vertical structure**: the relative position of the landscape elements is constant                    |
| A set of landscape elements (presence/absence of soils)                                 | **Landscapes with soils**: a set of landscape elements is parent materials, air, water, organisms, and soils                |
|                                                                                        | **Soils**: the presence of a loose organic and organo-mineral surface layer (humus, mull or peat horizon with living and dead organisms) that contacts the atmospheric air or surface water (the leaves and stems of rooted aquatic plants are both underwater and above it); these surface layer covers either rocks or one or more mineral horizons and the underlying rocks; mineral horizons differ from rocks in color, structure, composition, and other properties |
| Type of vertical structure of landscapes                                                | **Terrestrial landscapes**: formula of vertical structure                                                                 |
|                                                                                        | **Air | Soils | Parent rocks**                                                                                                                                 |
|                                                                                        | **Terrestrial soils**: probable soil stratification is not associated with regular deposition of lithogenic material on soil surface; local water saturation of soils is possible due to the large amount of precipitation or subsurface water outlet, however, the presence of a constant layer of water on the soil surface can only be short (several days) |
| Type of megarelief                                                                      | **Plain landscapes**: relatively flat fields with altitude deviations up to 300-400 m and predominance of slight slopes (not over 5°–10°) |
|                                                                                        | **Plain soils**: probable variable soil cover is not caused by spatial heterogeneity of rocks, frequent and strong change of exposure and degree of slopes |
| Zonal type of vegetation (in relation to macroclimate)                                  | **Middle taiga boreal forest landscapes**: coniferous, low shrub forests with green mosses and small grasses. Effective heat sum 1200-1600°C; growing period 100-120 days; average precipitation 500-600 mm/year; precipitation/evaporation ratio 1.5-2.0 |
|                                                                                        | **Middle taiga boreal forest soils**: moderately cold; occasionally waterlogged |
| Parent rocks: peat/not peat                                                             | **Not peat landscapes**: parent rocks are not peat deposits                                                               |
|                                                                                        | **Mineral soils**: upper horizon is humus, mull (muck) or peat; thickness of peat horizon <30 sm; the other horizons are mineral |
| Parent rocks: loose/hard                                                                 | **Landscapes on loose parent rocks**: parent rocks are composed of unconsolidated mineral grains and fragments of hard rocks |
|                                                                                        | **Soils on loose parent rocks**: soils have at least one horizon – humus, muck or peat                                      |
| Parent rocks: gravelly eluvium/not gravelly eluvium                                     | **Landscapes on gravelly eluvium**: parent rocks contain non-rolled fragments of unweathered hard rocks > 3 mm in size; the transition from eluvium to not decomposed hard rocks is gradual |
|                                                                                        | **Soils on gravelly eluvium**: stony, shallow, poorly differentiated; soil stoniness increases down the profile             |
4. Conclusion
The creation of multi-scale soil-landscape maps was made possible through the use of the systems approach, contemporary theories of classification, the hierarchical genetic Soil-Landscape Classification System developed on the basis of them, and GIS technologies. Due to the fact that they contain integrated information about soils and basic landscape elements, they can be recommended as the basis for creating a scientifically based hierarchical decision-making system for soil melioration at all levels (from global to local). Schematically the necessary conditions for creating a scientifically based hierarchical decision-making system for soil melioration are shown in figure 2.

Figure 2. Necessary conditions for creating a scientifically based hierarchical decision-making system for soil melioration.

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