Regional Approach to Soil Property Mapping using Legacy Data and Spatial Disaggregation Techniques

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Abstract

Current regional and national estimates of soil properties for the USA, such as organic carbon (SOC) storage or root zone available water capacity (AWC), are based on analysis of soil maps developed at a small scale and using methods that have considerable uncertainty. Recent improvements in the availability of detailed digital soils data, as well as computing capacity to handle large spatial data sets and statistical approaches to incorporate existing data in various formats, provide an opportunity to develop more detailed and accurate estimates of soil properties. Our objective is to improve the accuracy and precision of regional and national soil property estimates using spatial disaggregation techniques that combine detailed soil class maps with spatial data on environmental covariates such as topography and geology to discern the spatial distribution, variability, and extent of component soils--and the associated soil properties--within soil map units. A regional approach is employed based on recognized major land resource areas (MLRA), which are expected to have relatively consistent soil-landscape relationships. Two map units of large extent in the southern portion of the Eastern Allegheny Plateau and Mountains (MLRA 127) provide an illustration of the disaggregation approach to produce raster-based, landscape-scale maps of SOC. The disaggregated data identifies locations of component soils within soil class map units, depicting the spatial distribution of soils with higher and lower SOC stocks instead of using an average SOC value for the entire extent of a soil map unit. For this example, the disaggregated data predicted 6% higher average SOC content compared to the published soil class map data.

Key Words

GlobalSoilMap.net. digital soil mapping, soil organic carbon, soil survey, SSURGO

Introduction

The GlobalSoilMap.net project seeks to produce continental-scale maps of soil properties using a raster format. The anticipated soil property data layers are soil organic carbon (SOC) content, clay content, and bulk density, with additional properties such as carbon density and available water capacity (AWC) predicted using pedotransfer functions. These data are of interest to soil scientists and to other environmental scientists, modelers, and policy-makers.

In the United States, current regional and national estimates of soil properties, such as SOC storage or root zone AWC, are based on analysis of the USDA–NRCS State Soil Geographic Database (STATSGO2; Soil Survey Staff, 2006) (e.g., Bliss et al., 1995). However, STATSGO2 was developed at a small scale and the methods used to create STATSGO have considerable uncertainty. The impending completion of the initial soil survey of private lands in the USA will allow the more detailed Soil Survey Geographic Database (SSURGO) to be used to estimate soil properties. Because of its larger scale and finer detail, SSURGO based estimates of soil properties will be more precise especially when coupled with land use data and estimates of management induced differences in soil properties. Yet using SSURGO data to develop estimates of SOC, AWC, and other soil properties presents its own challenges. For example, artificial boundaries in the data associated with geopolitical boundaries lead to discontinuities in map unit composition and soil property data. Within SSURGO map units, unnamed components (e.g., components designated as "Other soils") are not included in the determination of soil properties, but may represent a significant proportion of map unit composition. Even when all components are named, the individual components can vary greatly in soil properties but the location of these components within the larger map unit delineation is not represented.

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The goal of this project is to improve the accuracy and precision of regional and national soil property estimates by developing models based upon SSURGO polygon data and data from USDA-NRCS and other databases. Our objective is to combine the SSURGO data with spatial data on environmental covariates such as topography and geology, to discern the spatial distribution, variability, and extent of the individual components within SSURGO map units. Digital soil mapping techniques will provide added value soil survey data to meet the needs of a wider user community. These products will include disaggregated polygon maps (soil component maps) and soil property maps at a variety of resolutions. This approach will provide for more reliable data on soil properties, and give modelers, policy-makers, and planners better data sets to develop assessments and form public policy.

Methods

Digital soil mapping technology allows for the production of raster-based, landscape-scale predictions of soil classes or continuous soil properties at a variety of resolutions, and SOC density is a soil property that is of great interest to modelers, policy-makers, and planners. The methods and results presented here focus on SOC, but are applicable to the estimation and mapping of other soil properties.

The SOC stock calculated for a given SSURGO map unit represents an average SOC value based on all of the component soils identified in the map unit. However, each component, while not mapped spatially, often occurs in specific landscape positions. For example, a map unit may consist of two components, with the first is found predominantly on north-facing slopes and the second on south-facing slopes. In this case, slope aspect could be used to predict the distribution of these soils within the map unit. It has been shown that soil map units can be disaggregated into individual components based on soil-landscape relationships documented in existing soil surveys (Bui et al., 1999; Bui and Moran, 2001).

Regional Approach

Major land resource areas (MLRA) are “geographically associated land resource units” (USDA-NRCS, 2006) that have been established to aid in state, regional, and national planning. MLRA regions delineate areas with similar physiography, geology, climate, soils, and hydrology relative to agricultural productivity. For the US National Cooperative Soil Survey (NCSS), MLRA regions are the basis for all future soil survey updates and management. It is also expected that within MLRA, soil-landscape relationships and environmental covariates are mostly homogeneous, making MLRA regions useful subdivisions for development of spatial disaggregation rules and soil-landscape models based on relationships between soils and environmental variables. MLRA 127 (Eastern Allegheny Plateau and Mountains) was selected for this case study. MLRA 127 is located in the northeastern USA, including eastern West Virginia and central Pennsylvania, as well as parts of western Virginia, western Maryland, and southern New York. It covers 50,370 km^2, with a range in mean annual precipitation of 840 to 1,725 mm and a range in mean annual air temperature of 6 to 12°C. The steep slopes of this highly dissected plateau expose the level-bedded sandstone, shale, coal, and limestone strata that underlie this landscape (USDA-NRCS, 2006). The dominant soils across MLRA 127 are Ultisols and Inceptisols.

Environmental Variables

Terrain attributes were derived from digital elevation model (DEM) data acquired from US Geologic Survey National Elevation Dataset with a resolution of 30 m. Terrain attributes calculated from these DEM included slope gradient, slope aspect, profile (down slope) curvature, contour (cross-slope) curvature, total curvature, tangential curvature, and relative slope position. Hillslope elements, which are defined based on differences in slope steepness and slope curvature, were derived using the methods of Schmidt and Hewitt (2004).

SOC Estimation

Initial SOC estimates were calculated using the methods of Bliss et al. (1995) using published SSURGO data. The SSURGO databases report a high, a low, and a representative value of soil organic matter for each soil horizon. These values are converted to SOC values by dividing by 1.724 (Soil Survey Laboratory Staff, 1996). The SOC content of each horizon (to a depth of 20 cm or 100 cm) was calculated using SOC content, bulk density, thickness, and rock fragment content data of each horizon. The SOC content of each horizon was summed over the prescribed depth to determine the SOC content of each soil in the survey area. The SOC content of each map unit was then calculated as the weighted average of all the component soils represented in each map unit.

Spatial Disaggregation of SSURGO

Spatial disaggregation provides a process for separating soil map units into individual components. Our approach focused on the conversion of soil information encoded as unmapped entities (inclusions and minor components) within a map unit polygon to a sequence of component soils across the landscape. Soil-landscape patterns and relationships that are embedded in the soil map unit descriptions in soil survey reports or stored as a series of values within the USDA-NRCS National Soil Information System (NASIS) database were used to develop spatial disaggregation rules. These rules were applied to the SSURGO data and the ancillary digital data that are used to represent key landscape characteristics (e.g., slope gradient, slope aspect, landform elements) to map the spatial extent of individual components. Disaggregated component soils were assigned SOC values derived from SSURGO database for the same named components. These raster maps were produced with a horizontal resolution of 30 m.

Results

Two map units of large extent in the southern portion of MLRA 127 (Fig. 1a) provide an illustration of the disaggregation approach. The Gilpin-Laidig association is mapped across 40,530 ha in MLRA 127. According to the Soil Survey of Webster County, WV (Delp, 1998), this map unit consists of about 45% Gilpin soils, 35% Laidig soils, and 20% other soils. The Gilpin soils are typically found on upper backslopes, while the Laidig soils are found on the lower backslopes. The other soils included in this map unit are the Cateache and Dekalb soils on ridges and shoulders, the Guyandotte soils in north-facing hollows and footslopes, the Meckesville soils on lower backslopes, Pineville and Shouns soils in south-facing hollows and footslopes, and Craigsville soils in drainageways. The Pineville-Gilpin-Guyandotte association is mapped across 18,098 ha in MLRA 127. According to the Soil Survey of Webster County, WV (Delp, 1998), this map unit consists of 35% Pineville soils, 25% Gilpin soils, 15% Guyandotte soils, and 25% other soils. The Pineville soils are typically found on lower backslopes and south-facing hollows, the Gilpin soils are found on upper backslopes, and the Guyandotte soils on north-facing upper backslopes and north-facing hollows. The other soils included in this map unit are the Dekalb soils on ridges and shoulders, the Laidig soils on footslopes, and Craigsville soils in drainageways. These descriptions were used to develop the spatial disaggregation rules to be applied to the SSURGO data (Fig. 1a) and the various DEM derivatives to develop disaggregated component soil maps (Fig. 1b). For example, if an area is mapped as Pineville-Gilpin-Guyandotte association and the DEM-derived hillslope element is a north-facing lower backslope, then that grid cell is designated as Guyandotte. However, if an area is mapped as Pineville-Gilpin-Guyandotte association and the DEM-derived hillslope element is shoulder, then that grid cell is designated as Dekalb.

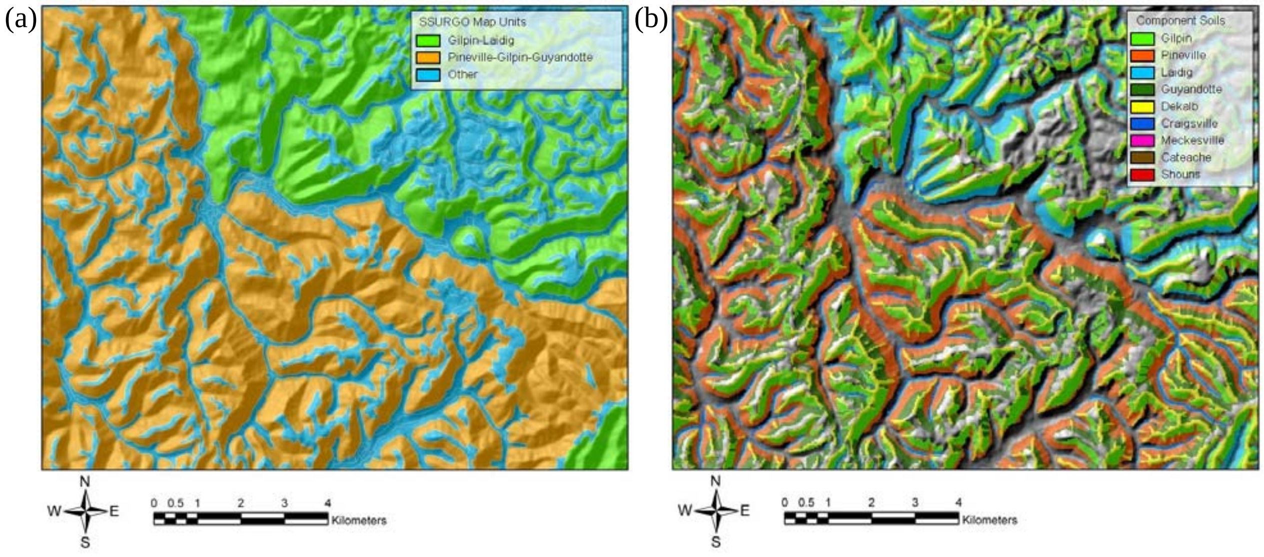

Figure 1. An example of (a) the published SSURGO data for a portion of southern MLRA 127 showing the large extent of the two survey map units and (b) the disaggregated component soils for this same area.

Each of the soils in the SSURGO map units have different amounts of SOC. When estimating SOC stocks from the SSURGO data the lack of spatial representation of component soils leads to a lack of spatial detail in the representation of SOC stock by the SSURGO data (Fig. 2a) because an average value for the entire map unit must be used. Using the disaggregated soils map, it is possible to depict the locations of areas of soils with higher (e.g., Guyandotte) and lower (e.g., Gilpin) SOC stocks. As a result, the disaggregated data predicted a different amount of SOC for the area covered by the disaggregated map units. For example, for the Pineville-Gilpin-Guyandotte association, the disaggregated data predicted a 6% higher average SOC content compared to the published SSURGO data for the area.

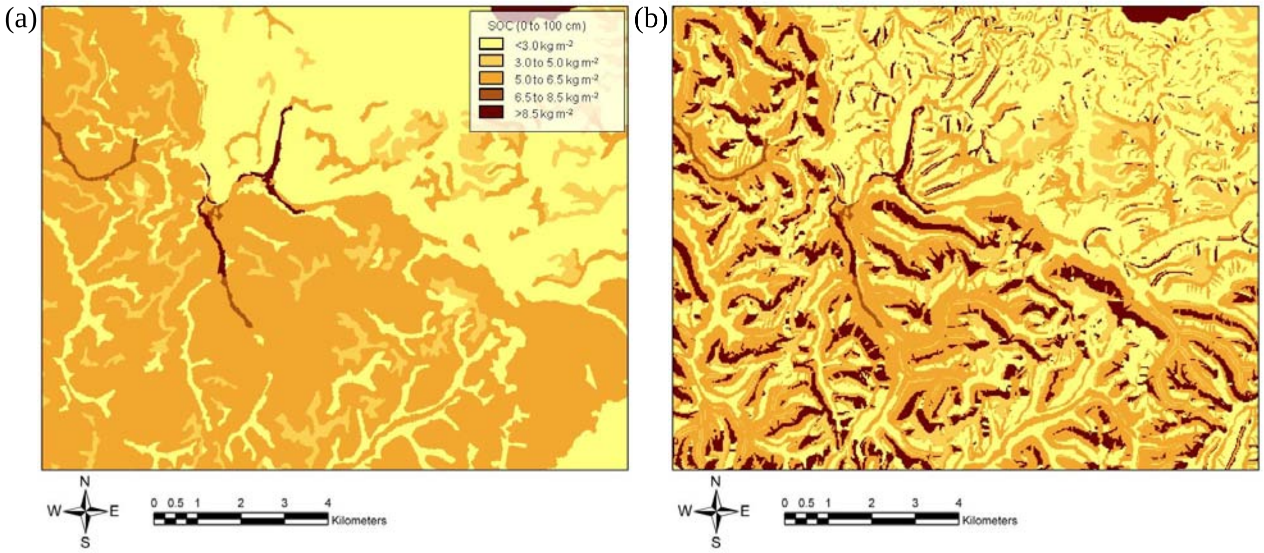

Figure 2. Calculated SOC stock in the upper 100 cm of soil as determined from (a) the published SSURGO data for a portion of southern MLRA 127 and (b) the disaggregated component soils for this same area.

Conclusion

Spatial disaggregation provides a methodology for representing the spatial distribution of component soils that are known to occur within a SSURGO map unit, including both the dominant soils and the included minor soils. Furthermore, the disaggregated soil map units can be used to represent the spatial distribution of soil properties that are associated with the component soils, such as SOC stock or root zone AWC. This spatial disaggregation approach will require an MLRA-wide examination of map unit composition and component landscape properties spanning the numerous soil survey areas within the MLRA. As a result, it will be necessary to harmonize information on soil map units, component soils, and component soil properties, including (i) correlating soil map units between existing soil survey area legends, (ii) updating geomorphic properties associated with each component soil, (iii) reconciling soil property values associated with component soils, and (iv) rectifying positional displacement of SSURGO map unit delineations compared to DEM-derived landform elements.

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