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Digital Soil Mapping: some issues of pedological concern

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PEDOMETRICS: INNOVATION IN TROPICS

Abstract
Aiming to contribute to the development and improvement of modern soil mapping techniques, an analysis of the basic concepts and practices adopted by the Digital Soil Mapping was performed, under the focus of pedological knowledge. The main deficiencies and inconsistencies concerning the Scorpan model and the conceptual approach of the method are identified and discussed. Some problems related to the soil maps produced are also pointed out. The importance of pedological knowledge for the development of soil mapping techniques and soil interpretation is emphasized, which in the authors' opinion should receive special attention from the scientific community dedicated to the topic.
Keywords: soil survey; soil genesis; pedological knowledge; scorpan model; soil science.

Introduction

Since its introduction (McBratney et al., 2003), the Digital Soil Mapping (DSM) has been considered a revolutionary approach, and its advantages and future perspectives frequently exalted (McBratney et al., 2019). Despite the large number of studies carried out in nearly two decades, there remains a difficulty in reconciling standardized procedure for a comprehensive application. Efforts in this direction have focused on the adequacy of statistical and computational techniques and selection of covariates; issues concerning pedological foundations have received little or no attention. In this sense, this work aims to evaluate some aspects of the DSM from a pedological point of view, as contribution to modern techniques of soil mapping.

Methodology

From a comprehensive evaluation of several studies applying DSM techniques, and having as reference review and synthesis papers and basic documents that present the fundamental principles of the method (McBratney et al., 2003; Dobos et al., 2006; SSDS, 2017; Rossiter, 2018, McBratney et al., 2019), an analysis of the main concepts, practices and results produced by the DSM methodology was performed, which are discussed below from the point of view of pedological knowledge.

Results and discussion

As proposed by McBratney et al. (2003), the basic principle of Digital Soil Mapping (DSM) is the use of environmental variables related to soil formation factors for prediction of soil classes or soil properties, based on the so called Scorpan model, which is used as a foundation to express quantitative evaluations in a spatial context.

This approach originates from a supposed similarity with traditional procedures of making soil surveys, which would involve a predefined model of soil formation applied to soil properties data and other environmental variables that have significant impact on soil formation (Dobos et al., 2006).

The Scorpan model is based on the fundamental equation of soil-forming factors, proposed by Jenny (1941). It is formulated as an empirical quantitative function S = f(s, c, o, r, p, a, n), where S (soil classes or soil attributes at a point in space and time) is estimated by seven environmental covariates — s: soil (other properties of the soil); c: climate; o: organisms; r: relief; p: parent material; a: age (the time factor); n: spatial position.

The genetic connotation implicit in the model is evident. In this sense, some questions arise. Given the great variability of environmental conditions related to soil genesis, and the strong interdependence among them, what are the objective conditions of establishing the formula factors in order to ensure reliable quantitative estimates? And how to take into account the interactions between the factors?

Besides the logical inconsistency of considering soil characteristics (factor s) as an independent variable in the equation, which implies a relationship of self-dependence in the genesis of a natural element (as something whose origin depends on itself), establishing the other factors on a quantitative basis seems a very complex problem. Thus, climate (climatic properties of the environment) and relief (landscape attributes) can be decomposed into a series of attributes, but how to quantify, or even to estimate, the participation of each one? On the other hand, organisms (vegetation or fauna or human activity) can be represented by vegetation or digital land cover data (SSDA, 2017); but how to take into account the influence of soil fauna constituents, microorganisms among them?

Even more difficult is to estimate the parent material, referred as lithology (McBratney et al., 2003), which can be derived from a geology map according to Soil Survey Manual (SSDS, 2017). At this point there is a contradiction between bedrock (lithology), the central theme of geological mappings, and parent material, as evidenced by the concept presented by the Soil Survey Manual itself (SSDS, 2017): “Soil parent material is not always residuum weathered directly from underlying bedrock. The material that developed into the modern soil may not be related to the underlying bedrock at all. In fact, most soils did not form in place but were subject to transport and deposition by wind, water, gravity, or human activities.”

However, the most complex and perhaps most important factor for an adequate adjustment of the equation is time (age), which has influence on all the others. From the variations in environmental conditions over the time of soil formation results the recognized soil polygenetic character, whose understanding requires specific and detailed studies of soil genesis. As reminded by Arnold (1999): "The exact combination of physicochemical and biological reactions that have actually transformed materials over time into soil horizons of a specific soil can never be known with certainty."

In summary, the Scorpan model presents a set of basic inconsistencies, both from the point of view of soil genesis knowledge and the specification of the equation parameters. Another problem of DSM conceptual approach refers to prediction based on soil genesis inferences, which presents a strong speculative aspect and incorporates a hypothetical character to the results obtained. Here, a word is necessary on the supposed similarity between DSM and traditional soil survey. It is important to highlight that the soil survey is based in relationships established between soils and other recognizable elements of the environment, evaluated directly in the field. This procedure does not exclude the use of soil genesis knowledge (and consequently of formation factors) to establish relationships between soils and other environmental variables — but its application should be restricted as an element of inference, not of determination. Although mental models are applied throughout the mapping work, they are progressively tested and refined in a continuous process of adjustment. For this reason, the detail level of the soil survey, more than the map scale itself, has an essential significance as an index of reliability and as a guide for interpretation of results. Even though subtle, this aspect implies a strong distinction between the traditional method of soil survey and the DSM approach. At the same time, it reveals a distorted understanding of the soil mapping process, which is reflected both in the digital methodological procedures and in its products.

In practice, for DSM predictions, the Scorpan model is just partially applied regarding the formula factors. While some factors (relief, for example) are decomposed into numerous attributes (environmental covariates), others are related restrictedly to one characteristic, or may not even be considered, which occurs frequently with the time factor (age). Each environmental covariate data (including soil) can be directly obtained by field determinations (soil profiles, for instance) or derive from remote or proximal sensing images, or even from thematic maps. Therefore, there are a large number of possible variations, regarding the nature of covariates selected, the information sources, the predictive models and the data processing techniques used. As a result, subjective conditions are incorporated into the process, whereas the results depend, widely, on the model adopted (subject of the action) as well as on the attributes, many of which are not directly related to the soil (object of the evaluation).

The high degree of subjectivity is expressed in the prediction differences observed in numerous digital mapping studies. This is one of the reasons for the difficulty of establishing a standard protocol for applying DSM. Such difficulty has been attributed to sampling deficiency, the need to adjust prediction models and covariate selection techniques, or even to hidden factors (Rossiter, 2018). Its causes, however, have much deeper roots. They result from inconsistencies of the DSM method discussed above, which in essence are linked to the disconnection with the pedological knowledge, the basis for understanding soils (Arnold, 1999).

In fact, some propositions adopted by the DSM evidence insufficient soil knowledge. Among them, the attribution of spatial resolution to soil maps (instead of scale) and the mapping of soil classes — both devoid of meaning. In the first case, a characteristic of sensor images (that record information captured from a real-world element) is applied to a thematic map, which corresponds to a representation of the geographic distribution of a natural element (not the phenomenon itself). In the second case, the fact that a soil class is just a concept, and as such impossible to map, is ignored. There is here a confusion, common to non-specialists, between taxonomic class and soil mapping unit as a landscape segment, which reinforces the importance of pedological knowledge for soil mapping and interpretation (Arnold, 1999).

The lack of perception of the inherent utilitarian character of soil maps is also explicit. This is exemplified by numerous DSM studies that present as product maps of soil classes at the order or suborder levels, which in themselves have no practical use. An eloquent example is the recent efforts to estimate the probability of occurrence of soil classes or properties. There is no technology that can solve the impasse concerning the practical use of maps indicating, for the same area, distinct possibilities of spatial distribution of soils (most probable and second-most-probable), as presented by McBratney et al. (2019; see Fig. 3).

Conclusions

The DSM approach presents a series of deficiencies associated to non-observation of knowledge developed by Pedology, which compromises its suitability as a methodology for soil mapping, which should be considered by scientific community related to the subject.

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