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Fuzzy Logic and Geostatistical Techniques for Spatialization of Soil Texture in Region with Rough Terrains

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Abstract

From the geotechnical standpoint, it is interesting to analyse the soil texture in regions with rough terrain due to its relation with the infiltration and runoff processes and, consequently, the effect on erosion processes. The purpose of this paper is to present a methodology that provides the soil texture spatialization by using Fuzzy logic and Geostatistic. The results were correlated with maps drawn specifically for the study area. The knowledge of the spatialization of soil properties, such as the texture, can be an important tool for land use planning in order to reduce the potential soil losses during rain seasons.

Keywords: texture of soil; geostatistic; kriging, infiltration, watershed management, Southeast Brazil

1. Introduction

Fuzzy systems, including fuzzy set theory and fuzzy logic, provide a rich and meaningful improvement, or extension of conventional logic. Applications in soil science, which may be generated from, or adapted to fuzzy set theory and fuzzy logic, are wide-ranging including numerical classification of soil and mapping, modeling and simulation of soil physical processes, fuzzy soil geostatistics, soil quality indices and fuzzy measures of imprecisely defined soil phenomena [1] Therefore, the objectives of this study

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were to use kriging to generate a spatial representation of soil properties expressed by numeric attributes, and to assess the uncertainty in estimates. Fuzzy logic was used to convert the soil textural classes in numerical values considering a small size area with a high geological and pedological heterogeneity.

This study area is situated within the Paraiba do Sul basin, southeastern Brazil linking the most important cities in the country (São Paulo and Rio de Janeiro). This region concentrates one of the largest industrial activities in Brazil along part of the Paraiba do Sul River. Nowadays, the landscape is a complex mosaic, dominated by pastures, followed by patches of forests, reforestation, agriculture, and urban areas. In the last decades, land use has changed significantly replacing degraded pasture with eucalyptus plantation especially in the mountainous regions.

2. Study Area

The study area comprises the region of Santa Edwiges farm (Fig. 1), inserted at upper region of Taboão stream watershed, Paraíba do Sul Valley, Southeast of Brazil. The area reflects the diversity in geology, pedology and geomorphology in the region, which characterizes the transition between the plains of the Paraíba do Sul Valley and the coastal mountain chain of Serra do Mar.

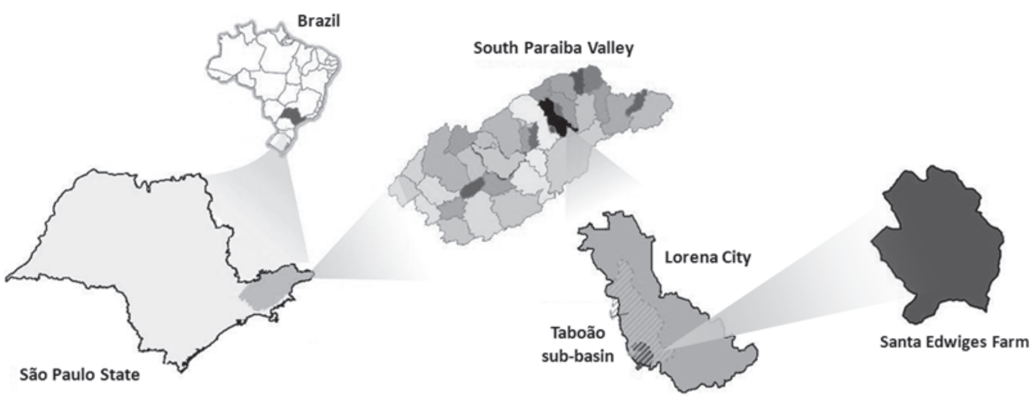

Fig. 1 - Location of the study area: Santa Edwiges Farm.

Santa Edwiges farm is entire inserted into a geological context formed by crystalline rocks of pre-Cambrian age [2] and includes various geological units (Fig. 2). The Northern portion of the area corresponds to the *Embu Complex*, which consists of metamorphic rocks (gneisses) having in its composition minerals more easily weathered such as mica and feldspar. The unit *Granitoid Quebra-Cangalha* occurs in the southern area. It is composed predominantly of white to grey leucocratic granites. Rocks of this unit are composed of minerals more resistant to alteration such as quartz and feldspar. The unit *Milonite* rocks occur in the middle of the area characterized by a well-developed foliation and well-structured and fine-grained minerals like mica and chlorite. The unit *Fluvial Terrace* and the unit *Unconsolidated Sediments* are associated with a fluvial plain Ribeirão Taboão and its main tributaries. In this area are identified paleo-terraces with pelitic sediment composition (silt and clay) and, secondarily, sand and angular pebbles of quartz and feldspar. Dark-colored sediments are also observed indicating the presence of rich organic soil [3].

Regionally, this area is inserted in the geomorphological unit of Mid Plateau of the Valley of *Paraíba do Sul* which was described in the Geomorphological Map of the State of São Paulo[4]. The diversity of geological substrate as described above is directly responsible for the wide variation of reliefs and soils found in the Santa Edwiges farm. On the scale adopted (1:10.000), it was possible to identify, on the basis of morphometric elements of terrain (hypsometric and slope) three distinct geomorphological units: Ridge Escarpments, Mountain with Moderate to Gentle Hillslopes and Plain Terraces.

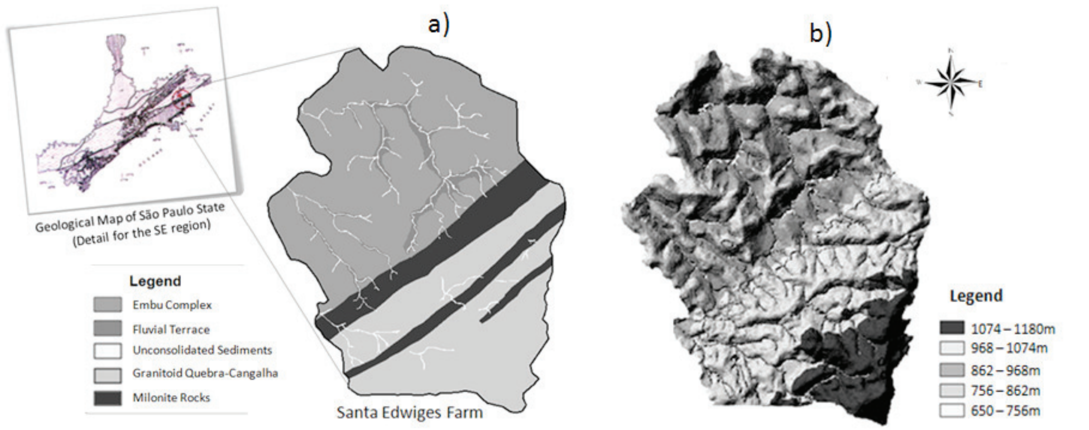

Fig. 2 - a) Geological Map of Santa Edwiges farm, 1:10.000 scale[5] and b) Hypsographic Map, 1:10.000 scale[6].

3. Methodology

A total of 41 samples were collected throughout the study area, at shallow depth. The sampling process sought to include all geological and geomorphological units in order to be more representative as possible for the great diversity of the study area (see Fig. 3).

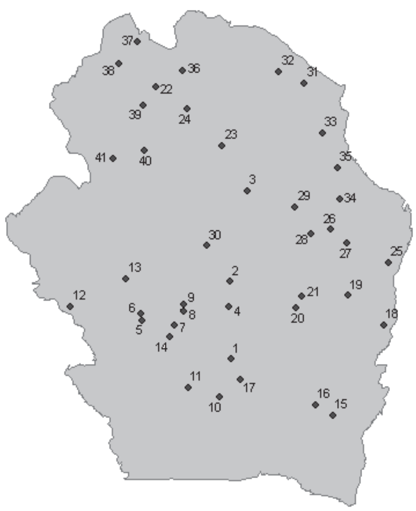

Fig. 3 – Location of the 41 samples collected in the study area.

In sequence, each sample was analyzed according to the textural classes (sandy, silty or clay). This classification procedure was carried out based on ASTM D2488, Standard Practice for Description and Identification of Soils - Visual-Manual Procedure [7] using the Unified Soil Classification System (USCS) to identify the soil classes. The main factors analyzed were: a) the color of soil samples; b) manual and visual inspection to identify primary minerals (mainly quartz) in after break-up and loosen the soil texture with the hands; c) dry resistance (aggregation) and adhesion of particles when wetted, in order to identify their plasticity. As regarding these parameters, sandy and clayey soils tend to have different characteristics and behaviors. The visual-manual characteristics are discussed as follow:

(a) Color of soil - it was observed that predominantly clayey soils found in the study area tend to be redder, and darker tones if they have organic matter content. On the other hand, sandy soils tend to lighter shades ranging from white, gray, yellow and orange hues; (b) Visual analysis of the grains - the presence of coarse materials in large quantities (mainly quartz) correspond the soils with a large fraction of sandy. Moreover, the particles that make up clay soils are extremely thin and small, which make practically impossible their identification from naked eye. (c) Dry resistance and the aggregation - the attraction between the particles of clay (physico-chemical interaction) characterize the cohesion of the aggregate, what makes it more resistant. On the contrary, the sandy and silty soils crumble easily when one try to break up them manually. On the contact with water, clayey soils and others with a high content of organic matter show a plastic behavior; then it is possible shape it easily. This fact is not true for sandy soils.

From this analysis, the textural classes could be converted in numerical values (fuzzy values), using the fuzzy logic concept. Thus, two extremes were established, representing predominantly sandy soils (values near from 0) and clayey soils (values near from 1). All samples were classified numerically according to their degree of relevance on the texture (Figure 4).

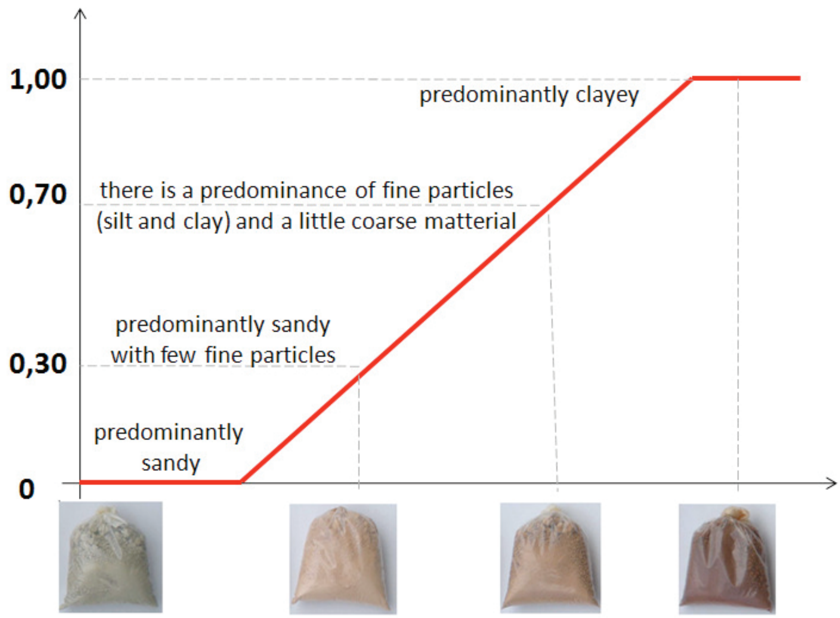

Fig. 4 - Converting of the textural classes of soil using fuzzy logic.

4. Results and Discussions

By the methodology described previously, all samples have a numerical value to represent its textural class (fuzzy value), as presented in the Table 1. The next step was to analyze the spatial characteristics of the variable (texture) in order to verify the viability of the spatial interpolation of data by kriging. To apply this geostatiscal method, it is necessary that the spatial distribution of the variable (texture) meets certain geostatistical assumptions. Geostatistics uses the technique of variogram (sometimes called semivariogram) to measure the spatial variability of a regionalized variable, and provides the input parameters for the spatial interpolation of kriging [8]

Table 1- Fuzzy values representing the soil texture for all samples. Values near from 0 (zero) indicates sandy soils whilst values near from 1 (one) indicates clayey soils. The location of each sample could be seen in the Fig. 3.

Sample	Texture (fuzzy value)	Sample	Texture (fuzzy value)	Sample	Texture (fuzzy value)	Sample	Texture (fuzzy value)
1	0,2	11	0,8	21	0,3	31	0,2
2	0,5	12	1,0	22	0,9	32	0,9
3	0,4	13	1,0	23	1,0	33	0,2
4	0,2	14	0,3	24	1,0	34	1,0
5	0,5	15	0,3	25	1,0	35	1,0
6	0,9	16	0,1	26	0,0	36	1,0
7	0,8	17	0,0	27	0,4	37	1,0
8	0,0	18	0,1	28	0,8	38	0,9
9	0,9	19	0,0	29	0,7	40	1,0
10	0,1	20	0,0	30	1,0	39	1,0
						41	0,9

From the verification and settings of the semivariogram presented in Fig. 5a, the *Geostatistical Wizard* tool is able to generate the spatial distribution map of the texture, by interpolation of the spatial data. The result shows the variability of the texture in whole study area (Figure 5b)

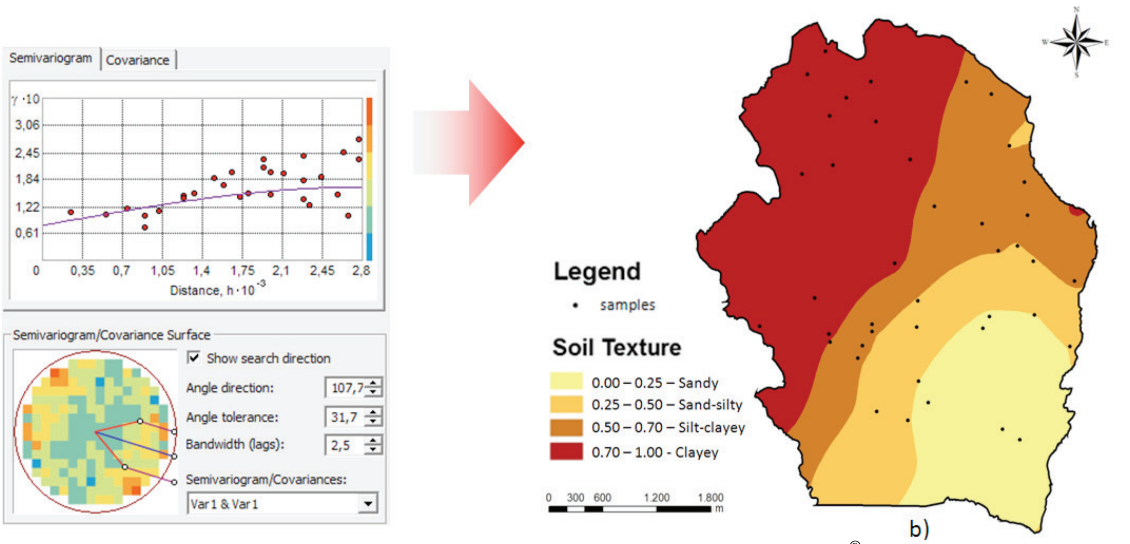

Fig. 5 – a) Settings for the semivariogram adjusted for the soil texture, by using ArcGIS® 9.2. and b) Spatialization of the soil texture obtained by kriging.

Comparing the spatialization of the soil texture (Figure 5) with geologic map (Figure 2), the results present spatial patterns of texture which is consistent with soil types expected for the geologic and geomorphological characteristics found in the study region. The countour map of kriging variance indicates predominance of sandy soils in the southern region, which corresponds to the geological unit "Granitoids Quebra-Cangalha", composed mainly of leuco-granite. The soils from this unit tend to have large amount of coarse material (sand), thin layer, and large heterogeneity. According [9], these soils are classified as Cambisols. On the other hand, in the northern region, kriging results indicated the presence of soils with high clay content, which correspond to the "Embu Complex". This unit is composed mainly of gneissic rocks rich in biotite. The soils of this unit tend to be well developed, mature residual soils, clayey, thick and high homogeneity, and are classified as Latosoils.

5. Conclusion

Fuzzy systems, provide a rich and meaningful improvement or extension of conventional logic with large wide range application in soil science. The combination between kriging of soil variability and fuzzy logic allows better optimization of parameters modeling. Therefore, the methodology was able to predict, in a simple and practical manner, good quality results and consistent with the geological and pedological characteristics of the study area.

6. Acknowledgements

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