

THE USE OF SOIL-LANDSCAPE RELATIONSHIPS MODELLING AND GEOTECHNOLOGIES FOR DETAILING THE SOIL MAP OF DISTRITO FEDERAL IN BRAZIL

M.P.C. Lacerda^a, I.O. Barbosa^b, H.M.R. Alves^c, T.G.C. Vieira^d, P.R. Menezes^e

^a Universidade de Brasília - FAV Campus Darcy Ribeiro, ICC Sul, 90910-970. CxP 4508, Brasília, DF, Brasil - marilusa@unb.br

^b Departamento Nacional da Produção Mineral, Setor de Autarquias Norte, Brasília, DF, Brasil - inara@dnpm.gov.br

^c EMBRAPA Café, Campus da UFLA, CxP 176, 37.200.000, Lavras, MG, Brasil - helena@ufla.br

^d EPAMIG/CTSM, Campus da UFLA, CxP 176, 37.200.000, Lavras, MG, Brasil - tatiana@epamig.ufla.br

^e Universidade de Brasília - IG, Campus Darcy Ribeiro, ICC Centro, 90910-970, Brasília, DF, Brasil - pmenezes@unb.br

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ABSTRACT:

The population growth in the Distrito Federal has led to indiscriminate occupation and use of its lands. To evaluate the current conditions of the environment, the maps of the region's natural resources, especially its soils, must be updated and detailed. The objective of this work was to detail the available soil map Distrito Federal and to generate a preliminary soil map at the scale 1:25.000. A study area, representative of the region's geomorphologic surfaces, geologic units and soil classes, was selected. This area included the IBGE topographic maps of Sobradinho, Granja do Torto, Rio Sonhim and Chapada de Contagem, at the scale 1:25.000. Basing on information from the literature and sound field work, the relations between geology, geomorphology and the soils formed in the selected area were studied to develop a geologic-geomorpho-pedologic model, which represented the geography of the soils over the regional landscape. The available geologic map of the Distrito Federal, scale 1:100,000 and the Digital Terrain Model (DTM) and a slope class' map, both generated in this work at the scale of 1:25,000, were used as the basic thematic maps for the modelling process in the GIS. The model was used to improve the detail of soil mapping and classification, and an updated soil map of the Distrito Federal at the scale of 1:25.000 was generated. The more detailed soil map obtained by geotechnology and modelling was checked in the field and proved to be more satisfactory for serving as a basis for environmental sustainability studies.

1. INTRODUCTION

The characterization of a region's environment is extremely complex because it involves a study of all its natural resources. To deal with this complexity, these resources must be separated into more homogeneous segments, a process in which soil survey is an important tool (Resende, 1983). An understanding of the physical and chemical characteristics of the different soil classes is necessary to the preservation of these natural resources and forms the basis for any sustainable agricultural activity.

The traditional methodologies for soil survey are costly and time consuming. Models that predict the distribution of soils in the landscape speed up and improve survey and classification, allowing also for the application of the results in other similar ecosystems (Resende, 2000).

These predictive soil distribution models can be generated through relation studies between soil and relief classes and geologic units. The relation between the original material and the soils formed allows for the discrimination of the former from petrographic characterization of the original rocks, respecting the relief, which controls weather and exposure to bioclimatic agents (Resende et al., 2002).

Considering the factors of soil formation that influence the pedogenetic process, as well as the degree of weathering, the characteristics and properties of the soils formed can be predicted from the original materials (Resende et al., 2002).

The Geographic Information System (GIS) has become an essential tool in the development of these predictive models of soil formation and distribution. These systems manipulate data from different sources, such as topographic maps, geologic maps, satellite images, aerial photographs, among others, combining information and carrying out different kinds of environmental analyses (Alves, 1990; Assunção et al., 1990; Goodchild, 1993).

In Brazil there are already many professionals working with geoprocessing and most of them use these systems. In the literature there are many works that use GIS technology, with different methodological applications, in the characterization of natural resources. Among these we can cite Andrade et al. (1998), Lacerda (1999, 2001) and Silva (2003). In these works, the environment was modelled quickly and safely and the mapping of study areas' soils was carried out through relations between the geology, the geomorphology and pedology of the studied area, which from now on will be referred to in this paper as "*geologic-geomorpho-pedologic-relations*".

In the Distrito Federal (DF), the population growth has led to indiscriminate use and occupation of its lands and to the degradation of the environment, especially in the areas destined for agriculture. Due to these changes, the DF's environment must be re-evaluated to obtain a real picture of its current condition. A sound and efficient methodology, that generates a characterization of the natural resources in space and time and allows their constant monitoring and periodic update of information, must be established.

The objective of this work was to show more soil pattern detail of a study area of the original soil map of the Distrito Federal (DF), increasing the scale of mapping to generate a soil map of this area at the scale of 1:25,000 scale, using a geologic-geomorpho-pedologic model and geoprocessing. This map will provide a more detailed pedologic basis for environmental sustainability studies, especially the occupation and use of the DF lands.

2. MATERIAL AND METHODS

The area (742.76 km²) chosen for this study, considered representative of the region's geologic and geomorphologic units and soil classes, is located in the N-NW portion of the Distrito Federal. It is delimited by the coordinates 47°45'00" and 48°00'00" longitude W and 15°45'00" and 15°30'00" latitude S, taken from the topographic maps of the Brazilian Institute of Geography and Statistics – IBGE, sheets Sobradinho, Granja do Torto, Rio Sonhim and Chapada de Contagem, scale 1:25,000.

The secondary information on the Distrito Federal natural resources, particularly geology, geomorphology, soils, as well as the IBGE topographic maps, was analyzed. Then field surveys were carried out to define the study area.

Information on drainage network and contours was taken from the corresponding topographic maps. The geology data was taken from Freitas-Silva and Campos (1998). In the study area occur Metasedimentary Sequences of Grupo Paranoá and Canastra.

The Grupo Paranoá occupies approximately 65% of the total area of the Distrito Federal and it is possible to discriminate seven depositional sequences:

- **MPppc:** Carbonated Shale Facies: metashales, slates, metalimestones, metassiltites, lenses of limestone and medium textures conglomeratic quartzites and mylonitic quartzites.
- **MPpr4:** Loamy Metarhythmite Facies: loamy metarhythmites, composed by metassiltites, metashales and quartzites, with mylonites occurrence.
- **MPpq3:** Medium Textures Quartzites Facies: clear grey to white quartzites, well selected, lenses of metarhythmites and silty-loamy laminations in the base.
- **MPpr3:** Sandy Metarhythmites Facies: sandy metarhythmites, composed by quartzites, metassiltites, metashales, with banks of quartzites at the base. Many contraction cracks and dikes of sand occur.
- **MPpa:** Slate Facies: green and red slates, laminations of fine textures quartzites and metassiltites on the top.
- **MPps:** Metassiltite Facies: loamy metassiltites, locally rhythmic and lenses of medium texture quartzites.
- **MPpq2:** Quartzite Microconglomeratic Facies: medium to sandy quartzites, laminations microconglomeratic and lenses of metarhythmites.

The Grupo Canastra occurs on the northern portion of the area, and presents the following sedimentary sequences:

- **MPcf:** Phyllites and sericite and chlorites schists, carbonaceous phyllites, with lenses de metalimestone, mylonites close to the base and quartzites.
- **MPccf:** Calc-schists Facies: calc-schists with occasional collations of phyllites at the top.
- **MPcmx:** Mica-schists Facies: biotite-moscovite-quartz-schists, chlorite-schists, quartz-schists and mylonites.

The geomorphology data were based on Novaes Pinto (1994), who recognized in the Distrito Federal three geomorphologic surfaces, called Região de Chapadas, Área de Dissecação Intermediária and Região Dissecada de Vale. The study area spreads over the three surfaces.

The relief of Região de Chapadas (Geomorphologic Surface 1) is flat to gently undulating, with elevations over 1000 m, generally up to 1.300 m. The Área de Dissecação Intermediária (Geomorphologic Surface 2) corresponds to areas slightly dissected with smooth sloping relief with elevations between 1000 to 1150 meters, developed over slates, quartzites and metassiltites of Grupo Paranoá.

The Região Dissecada de Vale (Geomorphologic Surface 3), represented by depressions occupied by rivers, is more recent, having developed over lithologies of Grupo Canastra, with heights varying from 1000 until approximately 750 meters.

2.1 Geomorpho-pedologic modelling

The geomorpho-pedologic model was generated based on data found in the literature, especially in Martins (1998, 2000), Martins and Baptista (1998), Novaes Pinto (1994) and Freitas and Campos (1998), and checked by field work (Table 1). The model represents the distribution of the soil classes in the first categorical level, according to the Brazilian system of soil classification (EMBRAPA, 1999), throughout the relief units, represented by their slope classes.

2.2 Geologic-geomorpho-pedologic modelling

The model relating geology, geomorphology and soils presented in Table 2 was established through relations between the soils in Table 1 and their respective geologic substrates to establish a model that includes the soil classes in more detailed categorical levels of the Brazilian classification system. The geologic-geomorpho-pedologic relation was based on studies reported in the literature, such as Freitas and Campos (1998) and EMBRAPA (1978) and on field observations of 100 georeferenced points, among which, the representative soil profiles of the main soil classes were selected. These profiles were described, sampled for chemical and physical analysis, according to Lemos and Santos (1996), and classified according to EMBRAPA (1999). Through this model the Distrito Federal soils' map was generated. Therefore, although a sound field survey was carried to check the model of soil distribution, the precision of the generated map depends on the precision of the extracted data of topographic and geologic maps used.

2.3 Implementation of the digital database

The Arc View 3.2 software, coupled with the 3D Analyst and the Spatial Analyst, was used to process the spatial data.

The themes used were: Contours, elevation points and hydrology (scale 1:25,000), from the IBGE topographic maps (1984) and Geology (scale 1:100,000), available in the Hydro

geological and Superficial Hydrological Resources Survey (Freitas-Silva and Campos, 1998).

2.4 Data generation

With the contours, hydrology and elevation points data, a triangular network or TIN (Triangular Irregular Network) of the study area was generated using the Arc View 3.2 3D Analyst. The TIN was converted into grid using the Spatial Analyst module, generating the Digital Terrain Model (DTM). The model was reclassified in 3 classes: 1150-1304 m, 1000-1150 m and 725-1000 m, which correspond to the geomorphologic surfaces 1, 2 and 3 of the Distrito Federal presented in this work, generating the geomorphic surface map of the area, also denominated reclassified DTM. The area's slope class map was also generated from the DTM, through the Spatial Analyst module. It was reclassified in 5 classes, according to Table 1 (0-3%, 3-10%, 10-24%, 24-45% e >45%).

Slope Class (%)	Relief Class	Geomorphic Surface ⁽¹⁾	Soil Class (1 st categorical level)
0 - 3	Flat Top (plateaus)	Surface 1 and 2	Oxisols
3 - 10	Smooth Sloping	Surface 1, 2 and 3	Oxisols
10 - 45	Undulating to Steep Sloping	Surface 1 and 2	Inceptisols
10 - 24	Undulating	Surface 3	Ultisols and Alfisols
24 - 45	Hilly	Surface 3	Inceptisols
> 45	Mountainous	Surface 1, 2 and 3	Inceptisols, and Entisols (Haplustent + Tropsaprent)

Table 1. Relation between slope gradient, relief classes, geomorphic surfaces and soil classes of the study area

⁽¹⁾ *Geomorphologic Surfaces, according to Novaes Pinto 1994): Surface 1 – Flat regions, with altitudes varying between 1300 and 1150 m, Surface 2 – Regions of intermediate dissection, with altitudes varying from 1000 to 1150 m and Surface 3 – Regions of hydrologic dissection, with forms of undulated relief, with altitudes among 1000 to 750m*

2.5 Data manipulation

The relief class map was generated from the sum of the reclassified DTM (geomorphic surface map) and slope classes maps, using the Arc View 3.2 Map calculator. It was reclassified into 6 classes, which correspond to the result of the association between slope classes and geomorphic surfaces (separated by the hypsometry classes) and lead to the development of different soil classes, as shown in Table 1.

Using the Map calculator, the Distrito Federal soils' map was generated from the sum of the geological map in grid format and the relief class map, following the criteria established in Table 2. It was reclassified in 11 mapping units.

Using the software Arc View 8.3, the 1:100,000 geological map was enlarged into 1:25,000. The more detailed geological map was checked during the field survey and the scale conversion was considered suitable for the proposed work.

Geomorphic Surfaces	Slope class	Geologic domains ⁽¹⁾	Soil classes
Surface 1, 2, 3	0 - 10%	MPp	Typic Rhodustox + Typic Plintustox
Surface 1, 2, 3	0 - 10%	MP (Mpq3)	Typic Haplustox + Typic Troppsamment
Surface 1, 2, 3	0 - 10%	MPc (MPccx)	Typic Rhodustox
Surface 3	0 - 10%	MPc, MPp	Typic Rhodustox + Typic Cambustox
Surface 3	10 - 24%	MPp (MPpac)	Tropic Rhodustult + Tropic Haplustult + Typic Haplustept
Surface 3	10 - 24%	MPc (MPcf, MPccx)	Tropic Rhodustult + Ferric Haplustult + Typic Haplustept + Tropic Mollrendent
Surface 3	10 - 24%	MPc (MPcf, MPccx and Calc-Facies)	Tropic Rhodustult + Tropic Haplustult + Ferric Haplustult + Mollic Troprendalf + Tropic Mollrendent + Typic Haplustept
Surface 1, 2	> 45%	MPp	Typic Haplustept + Typic Haplustent + Typic Tropsaprent + Rocks;
Surface 1, 2	> 45%	MP(Mpq3)	Typic Haplustept + Typic Troppsamment dystrophic lépticos + Typic Haplustent + Typic Tropsaprent + Rocks
Surface 3	> 45%	MPp (MPpac), MPc (MPcf, MPccx and Calc-Facies)	Typic Haplustept + Tropic Mollrendent + Typic Haplustent + Typic Tropsaprent + Rocks
Surface 3	24 - 45%	MPc (MPcf, MPccx and Calc-Facies)	Tropic Mollrendent + Typic Haplustept

Table 2. Relation model used to correlate geomorphic surfaces, slope classes, geologic domains and soil classes of the study area

⁽¹⁾ *Geologic Domains, described by Freitas-Silva and Campos (1998): Domain 1 – MPp – Sequence sedimentary Paranoá (Mesoproterozoic-Neoproterozoic): MPpac: Shale carbonated Facies, MPpr4: Loamy Metarhythmite Facies, MPpq3: Quartzite Facies, MPpr3: Sandy Metarhythmite Facies, MPpa: Slate Facies, MPps: Metassiltite Facies and MPpq2: Quartzite microconglomeratic Facies; and Domain 2 – MPc – Sequence sedimentary Canastra (Mesoproterozoic): MPcf: Phyllites and sericites and chlorite-schists, MPccx: Calc-schists Facies and MPcmx: Mica-schists Facies.*

The soil map generated, considered as preliminary, was checked in the field using georeferenced data, as spatial information can be taken from the generated product using the Geographic Information System.

3. RESULTS AND DISCUSSION

3.1 Results of the geomorpho-pedologic modelling

The slope classes and the reclassified DTM maps of the study area were generated from the geomorpho-pedologic model established in Table 1. As modelling involves the combination of the slope gradient and hypsometry class maps, the relief classes map (Figure 1) was generated by their overlaying, after reclassification according to the rules established in Table 1.

The result obtained presents good relation with the soil distribution in the DF's landscape. However, the soil classes in the Distrito Federal could only be established in the first categorical level of the Brazilian Soil Classification System (EMBRAPA, 1999), which is not enough to separate and map with more detail the various soil classes that occur in the region.

The following soil classes were mapped in the first categorical level: Oxisols, Ultisols and Alfisols, Inceptisols and Entisols (Haplustent + Tropsaprent). The Oxisols presented greater spatial distribution, especially along the central-southern portion of the study area, occupying the geomorphologic Surfaces 1 and 2. These represent the Região Geomorfológica de Chapada, with elevations between 1300 and 1150m and the Região Geomorfológica de Dissecção Intermediária, with altitudes varying from 1000 m to 1150 m. At the borders of the plateaus of the first surface, where the slope gradient is higher, Inceptisols and Entisols (Haplustent + Tropsaprent) are observed.

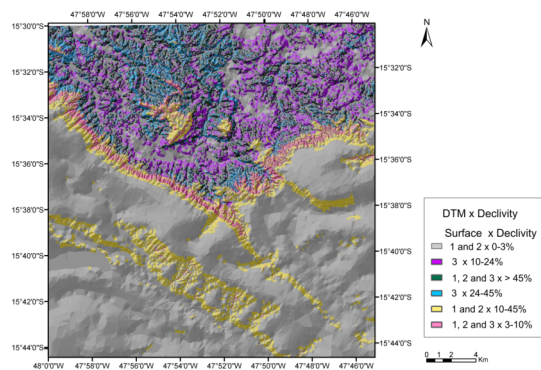


Figure 1. Relief classes map of the study area

The soils with argillic horizons (Ultisols and Alfisols) occur especially in the N-NW portion of the area, which corresponds to the Geomorphologic Surface 3 – Região Dissecada de Vale. This surface presents hilly relief with elevations between 1000 to 750m, and varying slope gradients, which characterizes gently undulating to mountainous relief. In the areas of higher slope gradients, Inceptisols and Entisols (Haplustent + Tropsaprent) occur.

3.2 Results of the geologic-geomorpho-pedologic modelling

To detail the soil classes according to the second and third categorical levels of the Brazilian Soil Classification System (EMBRAPA, 1999), geology data were used. As the soil is the final product of weathering of geologic material, its chemical,

physical and mineral properties can be inferred from an understanding of the geochemical and mineral composition of the former (Resende et al., 2002). This relation generates geologic-pedologic models, leading to the establishment of pedologic classifications in more detailed hierarchical levels.

The rules of the geologic-pedologic relations were based on these premises, backed by the literature and field checking in the study area, respecting the relief classes, in accordance with Table 2.

The soils' map was generated by the overlaying of the geologic map (Figure 2) and the relief class map created in this work (Figure 1) and was denominated Preliminary Soil Map of the Distrito Federal, presented in Figure 3.

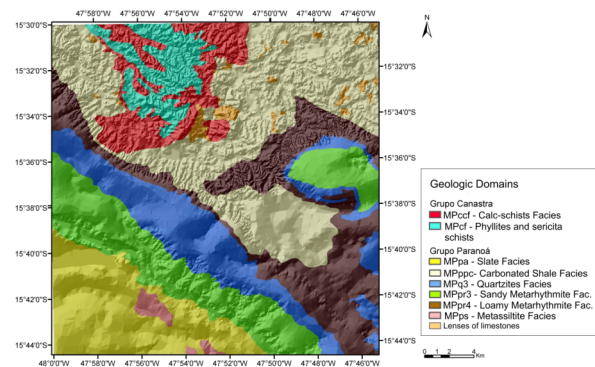


Figure 2. Geological map of the study area

Through this methodology, a better discrimination of the DF soil classes, classified in more detailed categorical levels by means of 11 mapping units, was possible. In other words:

- **Unit 1:** Association of Typic Rhodustox dystrophic + Typic Plintustox dystrophic.
- **Unit 2:** Typic Haplustox with inclusions de Typic Tropsamment.
- **Unit 3:** Association of Typic Rhodustox dystrophic + Typic Cambustox dystrophic.
- **Unit 4:** Association of Tropic Rhodustult dystrophic, eutrophic + Tropic Haplustult dystrophic, eutrophic + Typic Haplustept dystrophic, eutrophic.
- **Unit 5:** Association of Tropic Rhodustult dystrophic, eutrophic + Ferric Haplustult dystrophic, eutrophic + Typic Haplustept dystrophic, eutrophic + Tropic Mollrendent.
- **Unit 6:** Association of Tropic Rhodustult dystrophic, eutrophic + Tropic Haplustult dystrophic, eutrophic + Ferric Haplustult dystrophic, eutrophic + Mollic Trepndalf + Tropic Mollrendent + Typic Haplustept dystrophic, eutrophic.
- **Unit 7:** Association of Typic Haplustept dystrophic, eutrophic + Typic Haplustent dystrophic, eutrophic + Typic Tropsaprent dystrophic, eutrophic + Superficial Rocks.
- **Unit 8:** Association of Typic Haplustept dystrophic, eutrophic + Typic Troppsammept dystrophic leptic + Typic Haplustent dystrophic, eutrophic + Typic Tropsaprent dystrophic, eutrophic + Superficial Rocks.
- **Unit 9:** Association of Typic Haplustept dystrophic, eutrophic + Tropic Mollrendent + Typic Haplustent dystrophic, eutrophic + Typic Tropsaprent dystrophic, eutrophic + Superficial Rocks.
- **Unit 10:** Association of Tropic Mollrendent + Typic Haplustept dystrophic, eutrophic.
- **Unit 11:** Typic Rhodustox dystrophic.

Units 1 and 2 occupy a larger part of the study area, developing over Geomorphologic Surfaces 1 and 2 from loamy to sandy sedimentary sequence of Paranoá Group, respectively. Units 3 and 11, also constituted by Oxisols, develop over Geomorphologic Surfaces 1, 2 and 3 on loamy carbonated rocks of Grupo Canastra.

In the transition between Geomorphologic Surfaces 1 and 2, where slope gradient increases, units 7 and 8 develop, constituted mainly by immature and shallow soils and also superficial rocks.

Units 5 and 6, constituted by soils with argillic horizons, occur only in Geomorphologic Surface 3, following the slope criteria established for the development of this soil class according to Table 1. The are Argisols, mainly Ferric Haplustult and Mollic Tropicdalf, which have a direct relation to the geologic substrate, constituted by sedimentary rocks of Grupo Canastra with meta-limestones and schists of various geochemical composition. These parent materials are less resistant to pedogenesis than the lithologies of Grupo Paranoá, which predominate in the Geomorphologic Surfaces 1 and 2. These soils, that represent the region's highest natural fertility potential, present attributes inherited from the parent material.

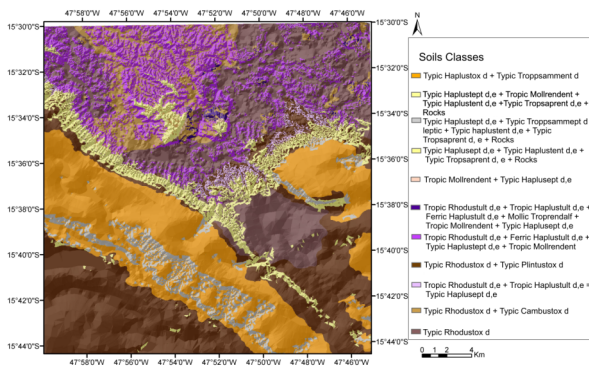


Figure 3. Preliminary Map of Soils of Distrito Federal

The remaining soil units mapped are distributed in areas with steeper slopes in the three Geomorphologic Surfaces.

The geologic-geomorpho-pedologic model used to generate the soil map represented satisfactorily the soils distribution in the DF landscape. In the Geomorphologic Surfaces 1 and 2 the model prevails in the flat tops of the plateaus and is also well corresponded in their borders, where shallow soils which retain close resemblance to the parent material occur.

The Geomorphologic Surface 3, in the study area, corresponds to the region's youngest surface, modelled by superficial erosion and desiccation processes. The geologic-geomorpho-pedologic relation presented good correspondence with the soils distribution in the regional landscape, both in relation to slope classes as well as the geologic domains.

Based on the data, the study area was divided in two main environments:

1. Geologic-geomorpho-pedologic environment Central-South: Geomorphologic Surfaces 1 and 2, represented by lithologies of Grupo Paranoá, with the development mainly of Typic Rhodustox, Typic Plintustox and Typic Haplustox and subordinately Typic Troppsamment, on the smoother slopes, and Typic Haplustept, Typic Haplustent and Typic Tropsaprent, on the steeper slopes.

2. Geologic-geomorpho-pedologic environment N-NW: Geomorphologic Surface 3, developed from lithologies of Grupo Canastra, over which soils with argillic horizons where formed, mainly Rhodustult, Haplustult, Ferric Haplustult and Mollic Tropicdalf, on undulating relief. On the rougher slopes, with hilly to mountainous relief classes, the soil classes Typic Haplustept, Typic Haplustent + Typic Tropsaprent, Tropic Mollrendent were observed and also rocks appearing at the surface. In the flat and smooth slopes the development of Oxisols, occasionally cambic, is observed.

The results show that the geotechnologies were cost and time efficient. Their use in the generation of environmental characterization thematic maps, although still preliminary, is effective and allows for corrections after field checking, as reported by Carmen Saiz and Valério Filho (1997) Áglío et al. (1997), Assad et al. (1998) and Bolfe et al. (1999).

The data generated subsidized the detailing of the soil map available, from the scale 1:100,000 (EMBRAPA, 1978) to the scale 1:25,000, as well as provided relevant information for the monitoring and sustainable use of DF soils.

Geomorpho-pedologic and geologic-pedologic modelling can be used to generate pedologic maps, as observed by Andrade et al. (1998), Lacerda (1999, 2001) and Silva (2003), making traditional soil survey and mapping more efficient. The results are in the same line as those found by Alves (1990), Assunção et al. (1990) and Goodchild (1993), for whom, by means of the Geographic Information Systems, it is possible to manipulate correctly thematic maps from various sources and to carry out different types of analyses. The accuracy of the generated maps, however, will depend on the accuracy of the secondary data available and on the established methodology and must be supported by sound field checking.

4. CONCLUSIONS

The relationships between geology, geomorphology and soil geography were used to identify, classify and map, at a more detailed hierarchical categoric level, the soil distribution of the Distrito Federal landscape. A geologic-geomorpho-pedologic model was used to generate an updated soil map at the scale 1:25,000.

The study area was segmented in two large environments: 1. Geologic-geomorpho-pedologic environment Central-South, with the occurrence of Typic Rhodustox, Typic Plintustox and Typic Haplustox and subordinately Typic Troppsamment, Typic Haplustept, Typic Haplustent and Typic Tropsaprent correlated to the Geomorphologic Surfaces 1 and 2, and developed from rocks of Grupo Paranoá; 2. Geologic-geomorpho-pedologic environment N-NW, with the occurrence of Tropic Rhodustult + Tropic Haplustult + Ferric Haplustult + Mollic Tropicdalf + Tropic Mollrendent + Typic Haplustept, Typic Haplustent + Typic Tropsaprent, and Rocks over Geomorphologic Surface 3, which were formed from lithologies of Grupo Canastra. The Distrito Federal soil map generated by modelling and geotechnology provides more detailed data for sustainable land use planning and management.

The geotechnologies and modelling methodologies used were effective in generating pedogenetic maps at larger scales, required for regional and local studies. It also benefits traditional soil survey and mapping in terms of time spent, costs and number of professionals involved. These maps can be used

for several purposes such as land evaluation and agricultural planning and other environmental studies.

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