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New Map Representation of Soil Results in the Environmental Geochemical Atlas of the Geological Survey of Brazil

Novo Modelo de Representação dos Mapas de Resultados de Solo nos Atlas Geoquímicos Ambientais do Serviço Geológico do Brasil – SGB-CPRM

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Abstract

Since the sampling of the first twenty centimeters depth in top layer of soil sampling points, aiming at environmental studies, it was necessary to find a way to represent these results in the soil maps of the Environmental Geochemical Atlas of the Geological Survey of Brazil (SGB-CPRM). It should not increase the number of maps per Atlas, and should be understandable and accessible to professionals of several disciplines, besides being compatible with more than 15,000 samples, already collected by the environmental geochemistry and medical geology project (PGAGEM) of the SGB-CPRM since its beginning in 2003. After studying how British and Chinese researchers developed ways of representation for similar surveys in their own countries, it was chosen to make a single map, representing the two samples, the superficial (Top) being represented by colored and varied points and the subsurface (Sub) represented by a raster surface generated by IDW compatible with the previously performed samples. A map of the Federal District of Brazil is shown as an example of the defined model.

Keywords: Regional geochemistry, Soil Maps, Environmental Geochemistry.

Palavras chave: Geoquímica regional, Mapas de Solos, Geoquímica Ambiental.

INTRODUCTION

All the soil sampling executed by the Geological Survey of Brazil (SGB-CPRM) in their geochemical surveys is traditionally carried out collecting the material from the top of the horizon B. However, the growing need for geochemical studies of an environmental nature, the fraction of the first 20 centimeters of the top layer soil has gained great importance. Following a worldwide trend, the SGB-CPRM opted for keeping the two samples at the same point, being the portion of the first 20 centimeters called Top and the deepest portion called Sub. The depth of the deepest part varies from country to country, being 35 to 50 cm in England and from 150 to 200 cm in China. In order to maintain the compatibility of results from older samples, the SGB-CPRM kept the top of the horizon B, with variable depth, as a parameter guide of the Sub sample collection.

This paper aims to demonstrate the form of presentation chosen for the maps that make up the Geochemical Atlas of the Department of Territorial Management, trying to achieve an ease assembly, clear information and simplicity of multidisciplinary interpretation of the results obtained.

HISTORIC OF DATA PRESENTATION MAPS

From 1992 to 2003, the geochemical urban soil mapping work was carried out in the United Kingdom by the British Geological Survey (FORDYCE *et al.*, 2005), which relates the surface samples (Top) to the deepest samples (Sub). There, the depths of 5 to 20 cm (Top) and 35 to 50 cm (Sub) were used, with 21 cities covered in the Geochemical Surveys of Urban Environments project (GSUE).

The samples were collected in a 0.5 x 0.5 km grid, in places with natural vegetation as close as possible to the center of the cell, in five aliquots located on the edges and in the center of a square of 20 m, joined together, homogenized, and a single aliquot was generated for each depth (Figure 1).

Most of the analyses were performed by X-Ray Fluorescence Spectrometry (XRFS), starting with 18 elements and passing at the end to 46 elements (Ag, Al_2O_3, As, Ba, Bi, Br, CaO, Cd, Ce, Co, Cr, Cs, Cu, Fe_2O_3, Ga, Ge, Hf, I, K_2O, La, MgO, MnO, Mo, Na_2O, Nb, Ni, P_2O_5, Pb, Rb, Sb, Sc, Se, SiO_2, Sn, Sr, Ta, Te, Th, TiO_2, Tl, U, V, W, Y, Zn, Zr).

The maps are displayed separately as raster surfaces generated by IDW (Inverse Distance Weighting) for Sub samples and as points with different symbol sizes, according to the element concentration for the Top samples (Figure 2).

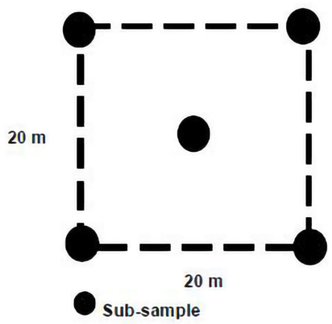


FIGURE 1 - Diagram of the composite soil sampling of the British Geological Survey for urban soils. (FORDYCE *et al.,* 2005).

Cheng *et al* (2014) performed the same type of work in 31 major Chinese cities, starting in the 1990s. The samples were collected in parks, cultivated land and roads, with heterogeneous distribution in a grid of 1 km² for surface samples, Top, from 0 to 5, 10 or 20 cm depth. The deep samples, Sub, were collected between depths of 150 to 200 cm, in an approximate grid of 4 km². Fifty-two elements were analyzed (Ag, As, Au, B, Ba, Be, Bi, Br, Cd, Ce, Cl, Co, Cr, Cu, F, Ga, Ge, Hg, I, La, Li, Mn, Mo, N, Nb, Ni, P, Pb, Rb, S, Sb, Sc, Se, Sn, Sr, Th, Ti, Tl, U, V, W, Y, Zn, Zr, Si, Al, Fe, Mg, Ca, Na, K and Total C).

They represent both results in a single map, being point values for the deep samples (Sub) and raster surface for the surface samples (Top) (Figure 3).

The SGB-CPRM, since its foundation 50 years ago, has traditionally carried out a simple soil sampling at the top of horizon B, where metals and clay-minerals from illuviation are naturally accumulated under the action of percolating water (ROSE; HAWKES; WEBB, 1979).

Although soil sampling is more common in the detail stage in a prospecting project, all the planning of the Low Density Geochemical.

Survey, started in 2003, uses as a model the survey of the state of Paraná, carried out by MINEROPAR and planned by Licht in 2002 (LICHT, 2005), with the collection of a sample always on horizon B, located in the center of each map of the continuous cartographic base in 1: 50,000

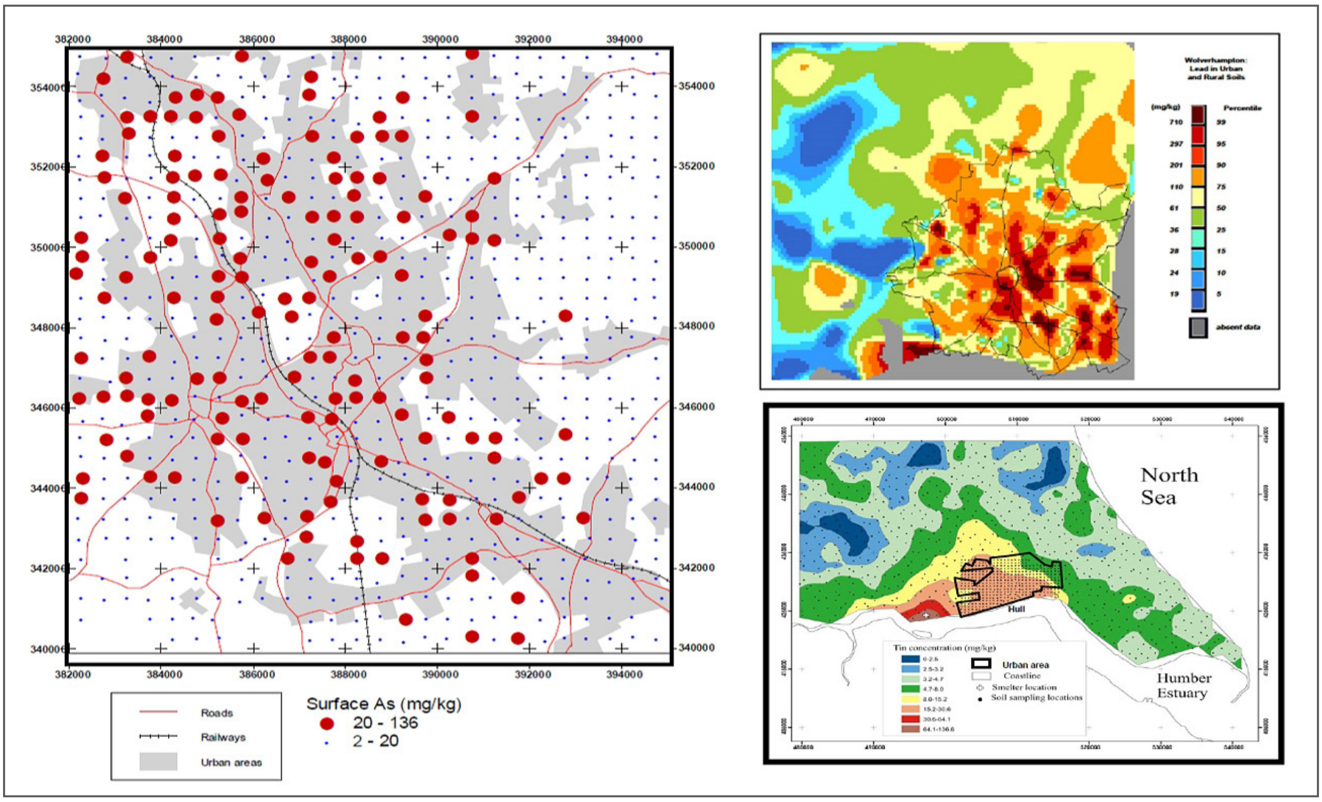


FIGURE 2 - Maps of Arsenic in surface soils in Stoke-on-Trent, Lead in deeper soils in Wolverhampton region and Tin in surface soil in Hull region. (FORDYCE *et al.*, 2005).

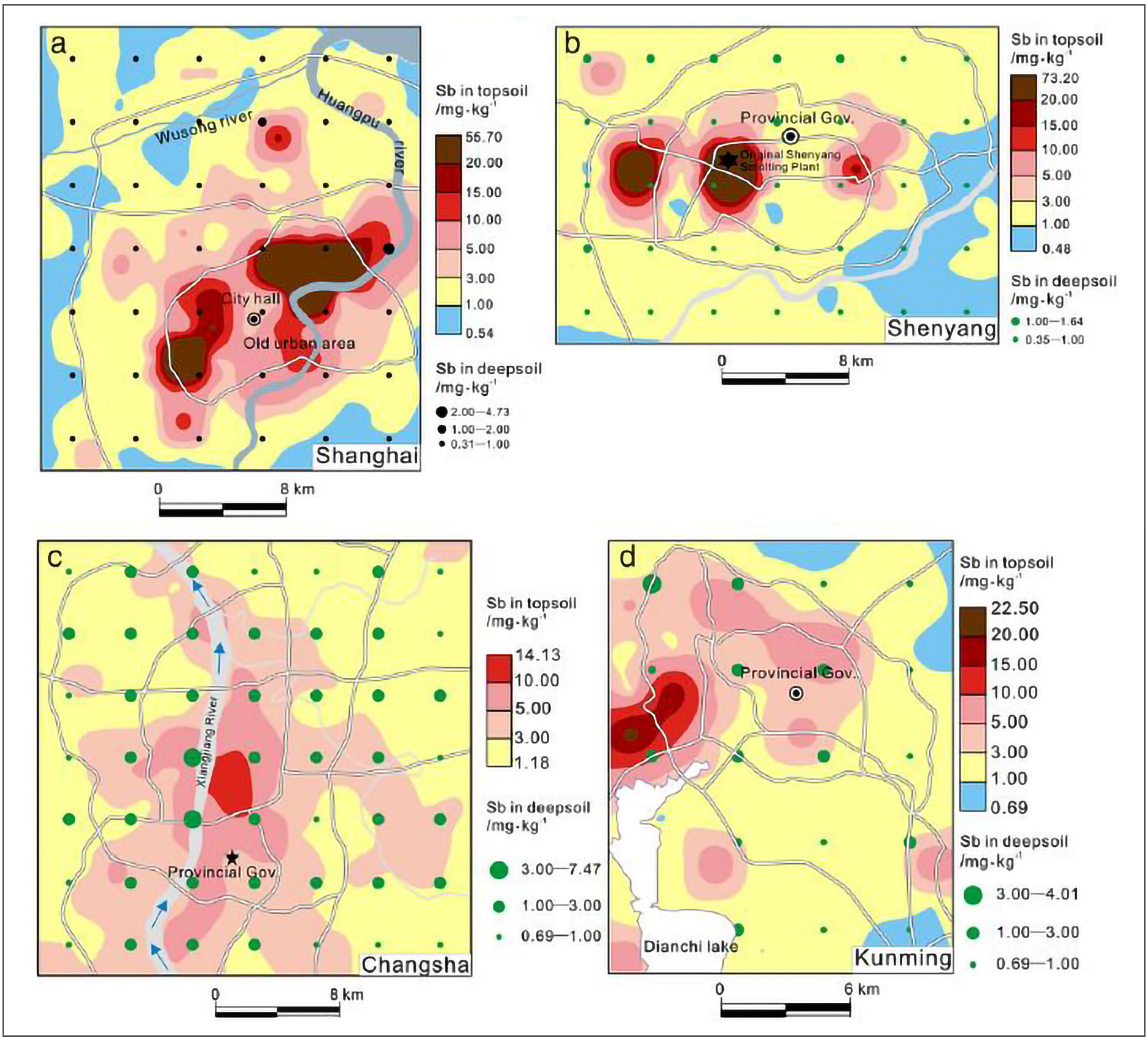


FIGURE 3 - Geochemical Maps for Antimony in four different Chinese cities. (Cheng *et al,* 2014)

scale grid (Figure 4) of the Brazilian Institute of Geography and Statistics – IBGE. The 1:100,000 scale map grid was also used (Figure 5). Later these aliquots can be joined to generate a sample per cell of 80x80km in the molds of the ICGP-259 and 360 projects (DARNLEY, 1995), in order to follow the precepts of the World Geochemical Map (Global Geochemical Reference Network).

In the Environmental Geochemistry and Medical Geology field, the Geological Survey of Brazil – CPRM has highlighted the Geochemical Survey Actions, with the Low-Density Geochemical Mapping Project in Brazil, which is in development since 2003, and aiming to evaluate, throughout the national territory, the composition of the rocky substrate, soils (25 x 25 km grid), active stream sediments (basin areas of 150 km²), surface waters (basin

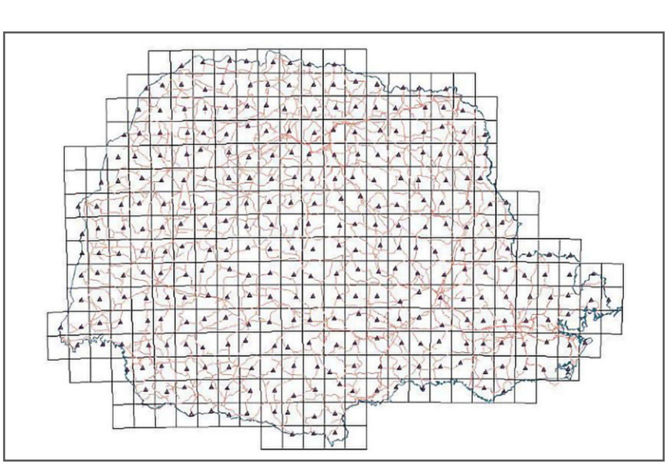


FIGURE 4 - Sampling soil Planning in the State of Paraná. One sample in the center o each 1:50,000 Map. (LICHT, 2005)

areas of 150 km²) and public supply waters in all the cities of the study region. About 40% of the national territory was already covered (Figure 6).

The project's main products are Geochemical Atlas with the distribution patterns of 27 cations (Al, As, B, Be, Ba, Ca, Co, Cd, Cu, Cr, Li, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Se, Si, Sb, Sn, Sr, Ti, V and Zn) and 7 anions (bromide, chloride, fluoride, nitrate, nitrite, phosphate and sulfate) in surface water and public supply water samples and 53 chemical elements in stream sediments and soil samples.

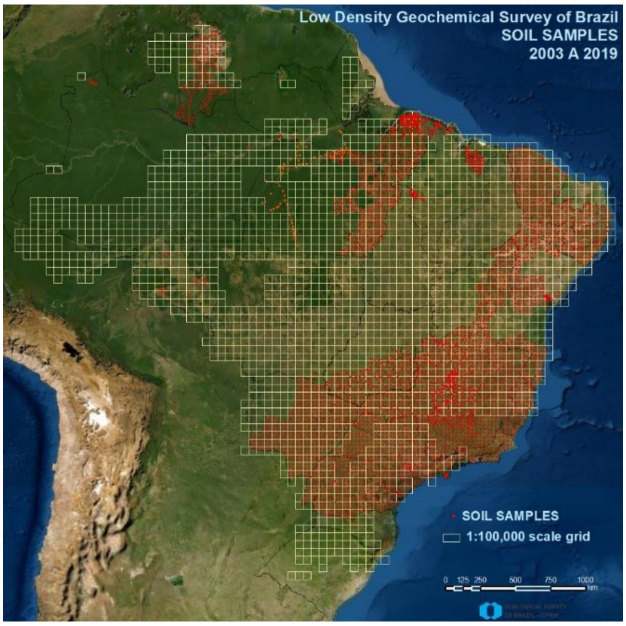


FIGURE 5 - Example of 1:100,000 scale grid in Brazil.

FIGURE 6 - Soil sampling already executed by SGB-CPRM in Brazil from 2003 to 2019.

From 2015, all the new surveys began to promote the collection of the Top sample, corresponding to the first 20 centimeters of the point to be sampled, whatever the type of horizon that is coming out, with the sample from the top of horizon B. The English and Chinese researchers mentioned above set a fixed depth for the sub collection. This procedure assists the logistic performance of a project, as all samples will be collected at a single depth. However, to keep consistency with the almost 15,000 samples already collected by 2015, it was agreed to continue collecting the deepest sample (Sub) looking for the top of horizon B.

In addition to the studies of States and large hydrographic basins, from 2018 on, the surveys were initiated to support geodiversity projects in micro regions, with adequacy of the work scale. The investigated drainage basins begun to have an average of 50 km² of influence area and the soil grid varied between 10 x 10 to 12.5 x 12.5 km, with collections of the Top and Sub samples.

The Geodiversity Project of Brazil is a very well successful initiative of the SGB-CPRM and have been carried out for 15 years, since 2006. Maps in scales of 1:5,000,000 and 1:2,500,000 covering integrally all the country and in 1:250,000 as well all the States and the Federal District are available in the internet page (www.cprm.gov.br) with their respective technical notes. The project defines geo-environmental formations relating regions to similar geology, geomorphology, biology, vegetation and land occupation, that might have similar problems, vulnerabilities, and need correct actions to promote the sustainable development in the region.

The geochemical survey executed as support in the Federal District Geodiversity Project, which covered the Federal Capital, Brasília, and several other cities from the metropolitan region, was the first work carried out with the new system and was used to delineated the base model from future surveys. The chromium soil map, published on the page 165 of the Technical Note of the Geodiversity of the Federal District (FERNANDEZ *et al.*, 2020), is presented as example.

MATERIALS AND METHODS

The soil sampling grid is variable approximately among 25 x 25 km for low density studies to 10 x 10 km for semi--detail survey to support geodiversity studies (Figure 7).

As the field team is very small (only 2 people) and the budget is short, the sampling locations are planning nearby to existent accesses. The sampling location chosen is preferentially covered by a natural vegetation and might have a visible soil profile (road cuts, trenches, natural slopes, etc.) where the top of horizon B can be seen (Figure 8). If it is not possible to find out a soil profile, a hole with a stainless steel auger drill with 0 to 20 cm depth should be done. After the collection of the Top sample, the drill hole continues until the material changes and indicates the possible presence of horizon B. When it is not visible, or is already outcropping, the collection is processed between 20 and 40 cm depth. (Figure 9).

The soil characteristics, the sample identification number and the coordinates of the sampling location are registered by an application designed by SGB-CPRM in a tablet, separately for the top and sub samples. These field data form the base of the project database without too much data manipulation after the collection.

In Laboratory the samples with approximately 2 kg were dried at 50°C, sieved at 80# and pulverized at 200#, digested with aqua regia and analyzed for 53 elements (Ag, Al, As, Au, B, Ba, Be, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Fe, Ga, Ge, Hf, Hg, In, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Ni, P, Pb, Rb, Re, S, Sb, Sc, Se, Sn, Sr, Ta, Tb, Te, Th, Ti, U, V, W, Y, Yb, Zn and Zr) by ICP-OES (inductively coupled plasma atomic emission spectrometry) and ICP-MS (inductively coupled plasma mass spectrometry).

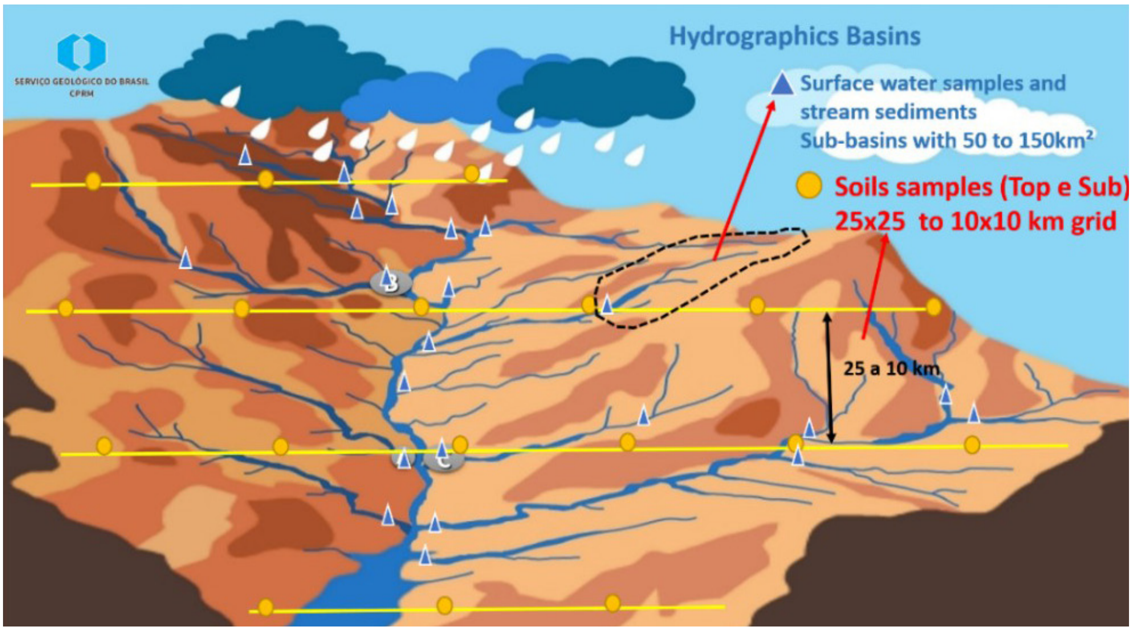


FIGURE 7 - Schematic figure with the sampling locations represented for low density and detail surveys.

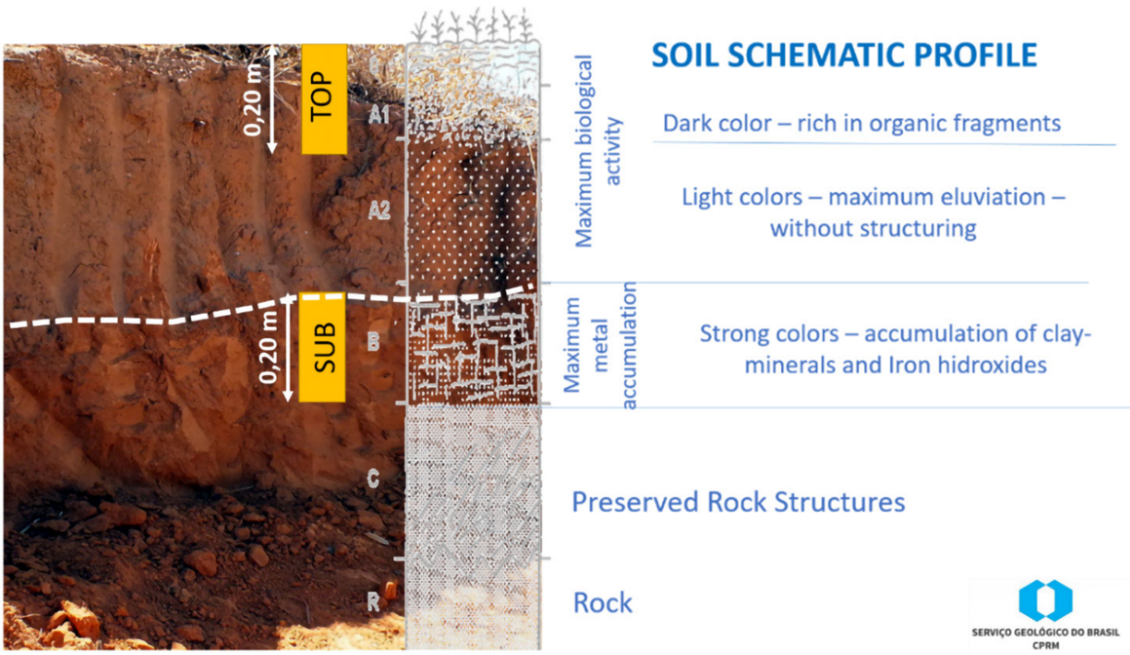


FIGURE 8 - Schematic soil profile with sampling locations.

FIGURE 9 - Auger drilling sampling. Picture by Aline Nogueira.

Every 20 samples, a field duplicate sample is collected at the two levels sampled. In all samples from horizon B are collected a third portion that is given to the Institute of Radiation and Dosimetry (IRD), our partner of the National Nuclear Energy Commission – CNEM. This aliquot is analyzed for radionuclides to create another specific Atlas from each State, with a definition of the State radionuclides background as the ones already done in Espírito Santo State (DUTRA GARCEZ *et al*, 2019), in Pernambuco State (LUIZ DO CARMO LEAL *et al,* 2020) and Alagoas State (FILGUEIRAS *et al,* 2020).

Statistical parameters taken from the boxplots (Figure 10), such as median, quartiles (25% and 75%), UW (Upper whisker) and IQR (Interquartile Range), were used on the maps to graduate the range intervals of the distribution of high and low concentrations for the 53 elements, using the ArcGis 10.8 software. The Sub results are represented by a digital surface (raster) and the Top results are represented by graduated circles (Figure 11), both are using the same color palette.

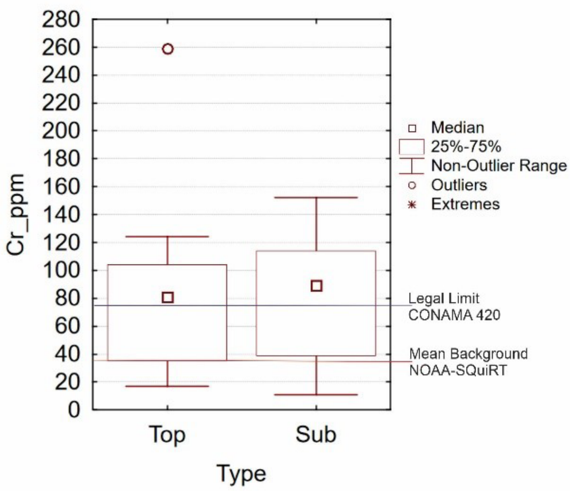


FIGURE 10 - Boxplot with the representation of the results of the Top and Sub samples (modified from FERNANDEZ, 2020).

The digital surfaces (raster), that represent the content distribution, were generated in the same software, through interpolation by inverse distance weighting (IDW), using interval ranges of <25%, 25%-50%, 50%-75%, 75%-UW and >UW of the data distribution. It is used the weight 2, a maximum search interval of 15 km limited to a maximum of 8 closest results.

As there are two populations of results related to the same sampling point, one to the Top and another to the Sub samples, tests were performed to define a coherent representation design, easy to visualize and that demonstrated the geogenic or anthropogenic character of the anomalies.

Statistical calculations were performed for the universe of Top and Sub samples populations separately and a single spreadsheet was created (Figure 12), with the addition of a column defining the sample type, with all the results, in order to allow the calculation of histograms (Figure 13) and boxplots grouped by sample type.

The geochemical results form a database that is available to every interested researcher in the format of an Atlas, spreadsheet and shape files. There are twelve Geochemical Atlas finished, five of them are from States (Ceará, Roraima, Pernambuco, Alagoas and Espírito Santo) and seven are from some specific areas very vulnerable or already impacted as Fernando de Noronha Island, the basins of Velhas river, Subaé river, Doce river, São Francisco river

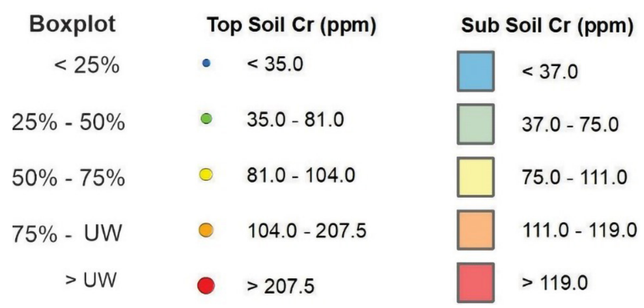


FIGURE 11 - Legend of the Sub and Top Samples with the predefined ranges (modified from FERNANDEZ, 2020).

Element	Cr_Top (ppm)	Cr_Sub (ppm)
Detection Limit	1.00	1.00
Observations Number	41	41
Results above Detection Limit	41	41
Average	77.85	79.37
Minimum Value	17.00	11.00
Maximum Value	259.00	152.00
Median	81.00	89.00
Standart Deviation	44.38	41.16
Legal v. CONAMA 420	75.00	
Legal v. VRQ FEAM-MG	75.00	
Mean NOAA-SQuiRT	37.00	

FIGURE 12 - Table with Sub and Top results (modified from FERNANDEZ, 2020).

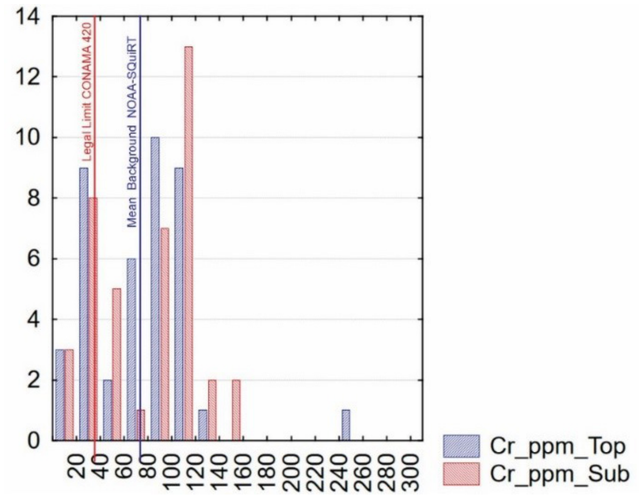


FIGURE 13 - Histogram of the Sub and Top results (modified from FERNANDEZ, 2020).

and Paranaíba river. This systematic mapping showed its great importance allowing to define the real environmental impact of the iron mine tailing dams rupture in the municipalities of Mariana (2015) and Brumadinho (2019) through the results obtained in the executed surveys before and after the dam rupture (VIGLIO; CUNHA, 2016, 2018). The Geochemical Atlas already published can be found on the internet page of the SGB-CPRM: http://www.cprm.gov.br/publique/Gestao-Territorial/Geologia%2C-Meio-Ambiente-e-Saude/Produtos---Geoquimica-Ambiental-4764.html

RESULTS DISCUSSION

The Federal District survey's database, was used as a model. In addition to the maps contained in the Technical Note of the Geodiversity of the Federal District Project, results are also going to be used in the assembly of the Federal District Atlas.

Usually, SGB-CPRM Atlas is made up of 164 maps, thus, adding 53 more maps concerning the new Top soil sample would not be suitable. The option was to place both results into a single map, such as in China, but with the representation of points for the Top samples and a representation by raster, simulating old isogrades maps, for the Sub samples, such as in England. The following points were defined to enable the assembly:

a. Maintain standard statistical intervals of the project (25%, median, 75%, UW) adding legal value of the element represented for both samples when possible.

b. Use the same color palette for raster intervals and proportional points.

c. Represent both populations separately in Boxplot and Histogram graphics and in the table with the main statistical parameters.

d. Represent as hatches with transparent backgrounds the impacted area, legal reserves and the built region.

e. Insert the shaded relief and a very discreet representation of the drainage network to the background.

f. Use the surface formations mapping for interpretation, when there is one, instead of the geology map, considering that the surface formations are directly related to the obtained results.

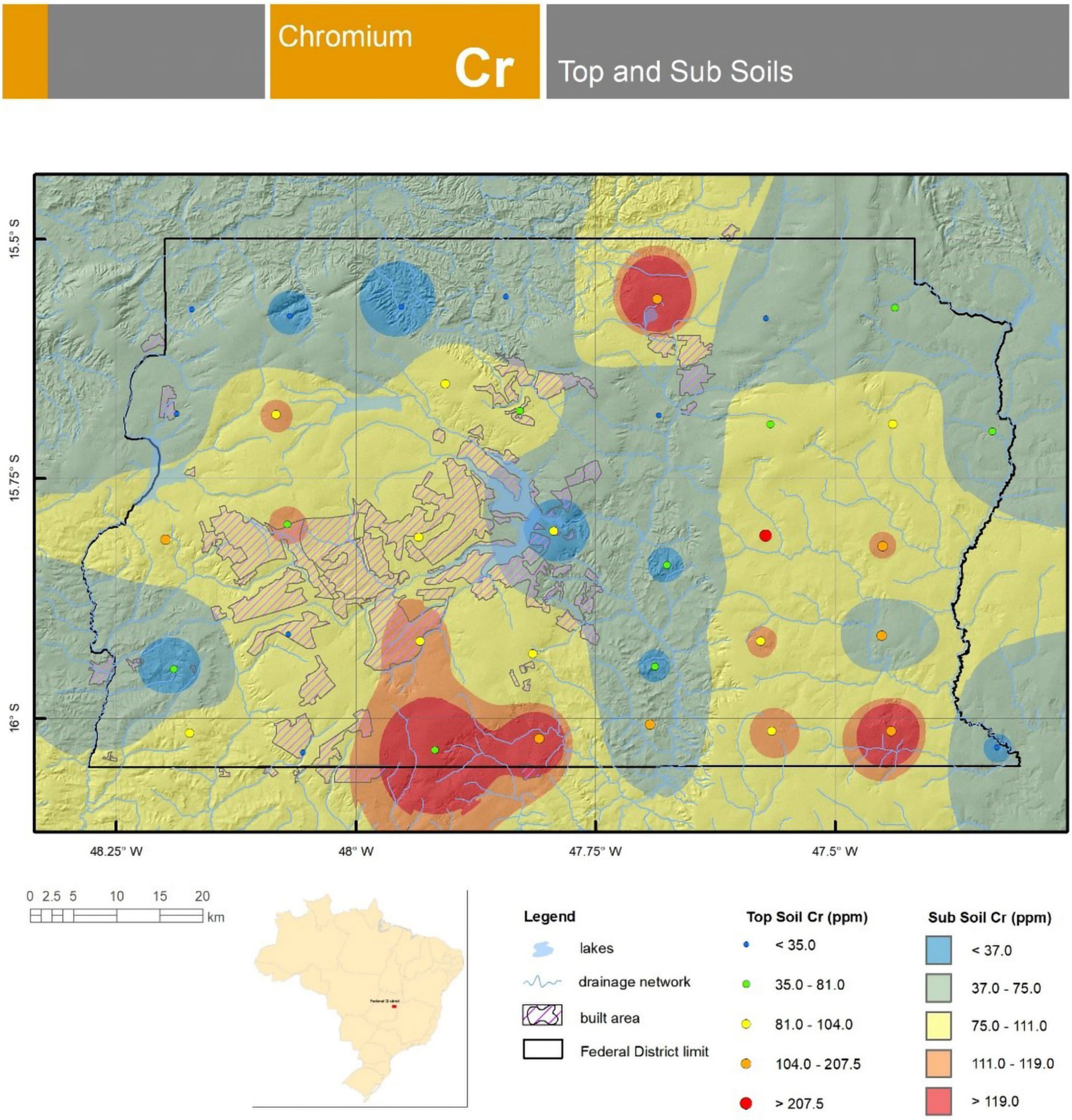
It will also be used, for results interpretation, the premise that in a normal soil profile without features generated by mineral deposits or anthropomorphic reasons, the values of Sub samples should always be higher than the values of Top samples.

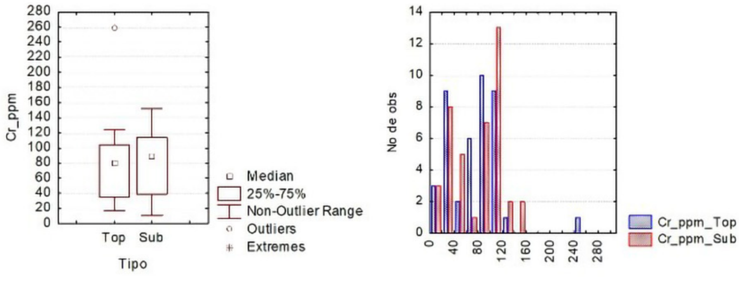
When the opposite occurs, or the surface value comes from some polluting source, or from some physical deposition related to sliding of slopes, colluvial deposits or other physical or chemical weathering processes that have enriched the element in the surface layer.

The final map of chromium shows three anomalous regions in red for the Sub samples with lower values for the Top samples (Figure 14, a, b and c), indicating possible geogenic source. However, in a region corresponding to the median-75% interval (yellow) there is an anomalous Top point, indicating a possible anthropogenic origin (Figure 14, d).

In this Cr map, only the blue area and points have a distribution pattern without any problem. The concentration in the green areas and points are above of the mean background concentration of the NOAA Screening Quick Reference Table (BUCHMAN, 2008) for inorganics in soil, and in the yellow, orange and red areas and points, the concentration are out of the maximum permitted values by the Brazilian legislation CONAMA (Environment National Council) 420 (Brasil, 2009) for both, sub and top soil samples.

The soil map presented, plus the maps of the other 52 elements, the maps of stream sediment and surface water, will be part of the Geochemical Atlas of the Federal District, currently in the process of construction.





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Standart Deviation	44.38	41.16
Legal v. CONAMA 420	75.00	
Legal v. VRQ FEAM-MG	75.00	
TEL NOAA-SQuiRT	37.00	

FIGURE 14 - Geochemical Map of Chromium of Federal District of Brazil, with results of Top and Sub soil sample. Source: Modified from Fernandez, 2020.

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