# Application of GIS Tools for Geotechnical Mapping - A Case Study in Brazil

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ABSTRACT: This paper describes the procedures and data processing performed to prepare geotechnical mapping for the city of Blumenau, Brazil, based on methods by Dias (1995). In order to develop the study, 27 watersheds were analyzed. Various sets of information were generated through geoprocessing resources: digital terrain modeling; hydrographic, hypsometric, slope, geological, lithological and pedological maps; a preliminary standard penetration test impenetrable layer and water level map; and allowable stress for direct foundation map. Outcomes include a formalization of the procedures adopted to obtain geotechnical maps for the city of Blumenau, which provide technical information to decision-makers, especially in organizing urban growth. In addition, the study presents the architecture of a rich tool for consultations, analyses, simulations, and maps involving alphanumeric information associated with geographic features.

## 1 INTRODUCTION

Digital maps have become strong allies for the storage and analysis of a growing amount of information, as they present greater potential for manipulation and more complex analyses. In recent years, Geographic Information Systems (GIS) have been used more intensely in supporting decision-making, presenting the necessary means to improve the efficiency in tasks that involve information contained in digital maps. GIS integrate graphical information and data in a single computational environment, thus enabling faster, clearer, and more complete troubleshooting involving a spatial environment, as well as punctual parameters to characterize them.

### 1.1 *GIS tools*

GIS are information systems enabling spatial analysis involving georeferenced data as their main feature. These tools can aid in creating scenarios and simulations based on observed spatial tendencies or in judging predetermined conditions, leading to basically descriptive data. Areas associated to geotechnical georeferenced data can also be applied. This data may refer to pedology, geology, lithology, geotechnical investigation sampling, terrain declivity, underground water level, physical and resistance parameters, and many other elements.

GIS have been used to create geotechnical maps as these systems present accessible and easily integrated data while being flexible to accommodate decision-making process needs, as well as to support the manipulation of a great amount of information simultaneously. The Brazilian Corporation of Agricultural Research (*Empresa Brasileira de Pesquisa Agrícola - EMBRAPA*) Information Technology Agency considers that GIS constitute a powerful tool for territorial management, enabling more precise and objective analyses that optimize both preventive and conservative actions. Maps enabling previous knowledge of soil characteristics in large-scale areas provide important information in aiding public planning for soil use and occupancy, as well as for implementing related public policies.

### 1.2 *Study area characterization*

The city of Blumenau is located in Santa Catarina state (SC), southern Brazil (Fig. 1), with total area of approximately 520 km², being 207 km² of which in urban areas and 313 km² in rural areas. The Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística - IBGE*) estimates the city population in 309,011 inhabitants.


Fig. 1 Location of the city of Blumenau
Source: www.orbituariosc.com

According to the city profiles published by IBGE, Blumenau has a rugged terrain mainly constituted by granite and gneisses rocks, with mountains in the south and valleys in the north. These characteristics foster serious problems from an engineering standpoint due to unplanned land occupation. In addition, the region is characterized by relatively high humidity and elevated rainfall rates.

The study area for the geotechnical mapping was defined as the city limits of Blumenau. Subsequently, the hydrological units defined by Agricultural Research and Rural Extension Agency (*Empresa de Pesquisa Agropecuária e Extensão Rural - Epagri*) within city limits were utilized to determine the main watersheds evaluated in this study. A total of 27 watersheds in Blumenau were analyzed, as presented in Fig. 2.

| Watersheds of Blumenau | |
|---|---|
| 1 | Blumenau |
| 2 | Cabeceiras do Rio Garcia |
| 3 | Colégio Normal Sagrada Família |
| 4 | Córrego Itoupavazinha |
| 5 | Córrego Jensen |
| 6 | Córrego Rua Brusque |
| 7 | Córrego Tatutiva Três |
| 8 | Córrego Tatutiva Um |
| 9 | Ilha Da Bela Vista |
| 10 | Margem Direita do Rio Itajaí Açu |
| 11 | Ponta Aguda |
| 12 | Ribeirão Branco, Ribeirão Fundos Pauxfune, Córrego Johann Olf e Salto Weissbach |
| 13 | Ribeirão Carolina |
| 14 | Ribeirão Chelter |
| 15 | Ribeirão da Velha |
| 16 | Ribeirão Fidelis |
| 17 | Ribeirão Fortaleza |
| 18 | Ribeirão Fresco |
| 19 | Ribeirão Kellmann |
| 20 | Ribeirão Luebke |
| 21 | Ribeirão Treze de Maio |
| 22 | Rio Garcia |
| 23 | Rio Itoupava Norte |
| 24 | Rio Itoupava Rega |
| 25 | Rio Salto do Norte |
| 26 | Salto Weissbach |
| 27 | Testo Salto |

Fig. 2 Analyzed watersheds – Blumenau

## 1.3 *Input*

The data used in this study were obtained from the Blumenau City Hall (*Prefeitura Municipal de Blumenau – PMB*) and IBGE, abiding by Terms of Use, as well as public information available online from Epagri, as shown in Table 1.

Table 1. Data, source, and description of input

| PMB | IBGE | Epagri |
|---|---|---|
| Topographic map \| 1:10.000 | Geological map \| 1:100.000 | Watersheds map \| 1:100.000 |
| Standard Penetration Test (SPT) reports \| 314 boring logs | Soil map \| 1:100.000 | |

# 2 DATA TREATMENT AND ANALYSIS

This section describes the procedures of geotechnical mapping in a GIS setting for the city of Blumenau, with complimentary analyses using the geotechnical engineering properties of soil from SPT (Standard Penetration Test) reports of its urban areas.

## 2.1 *Data treatment*

Given that reliable data is vital for geotechnical databases, official data sources and careful data treatment for compatibility was used in converting input data from AutoCAD filename extension (dgn/dwg) to ArcGIS (shp). This preliminary stage required large effort to ensure data compatibility with ArcGIS. To this end, a series of transformations were performed in the input CAD files, namely:

- Grouping by theme of homogeneous elements which were initially blended;
- Georeferencing of graphical elements from previously-known coordinates;
- Establishing continuity of interrupted lines;
- Closing and redefining of polygon elements previously represented as lines; and
- Removal of duplicates elements.

With the dgn/dwg files duly treated, the ArcCatalog software (ESRI 2010) was used to determine projection type, vertical datum, and georeferencing zone in files. The selected system was the Universal Transverse Mercator (UTM), using the geocentric reference system for the Americas SIRGAS 2000 and zone 22S.

## 2.2 *Database*

Geographical information is organized in layers, each corresponding to a certain group of related objects and their respective attributes. The GIS groups layers in order to create a single image.The database developed for this study contains information on: districts, hydrography, 5-meter contour lines, city and urban area limits, watersheds, geology, lithology, groundwater level, borehole depth, and standard penetration resistance (N-value).

## 2.3 *Data analysis*

Geotechnical mapping was performed employing methods by Dias (1995), consisting in techniques for the definition of geotechnical units based in pedological and geological knowledge. Due to the different mapping processes used, the intersection between pedology and lithology can result in zones where the geotechnical mapping is inconsistent.

These zones are known as "dark polygons". Hydrography and Digital Elevation Model (DEM) maps derived from the contour lines as well as declivity maps were employed to treatment inconsistencies, as depicted in Fig. 3.

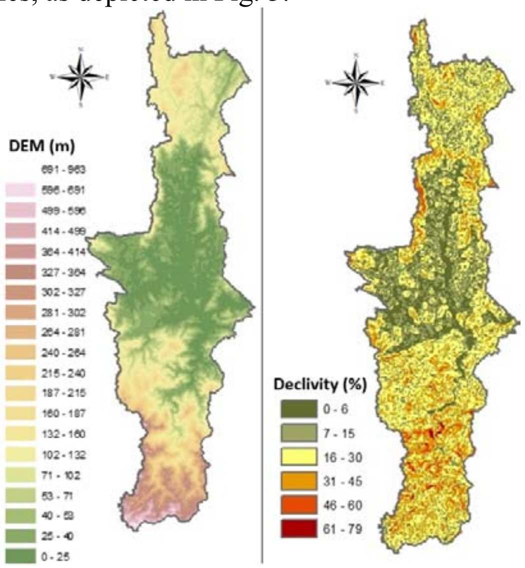

Fig. 3 Digital Elevation Model and Declivity

## 3 RESULTS AND DISCUSSION

This section presents maps detailing the results of the present study after the aforementioned data treatment.

### 3.1 *Themed maps*

The contour lines enabled the development of DEM and declivity maps as seen in Fig. 3, which, in conjunction to the region hydrography, aiding in creating an auxiliary tool in data analysis and treatment. Through these maps, e.g., it was possible to analyze consistency at cross-referenced lythology and pedology information through these maps in order to adjust areas identified as inconsistent. The resulting map can be seen in Fig. 4.

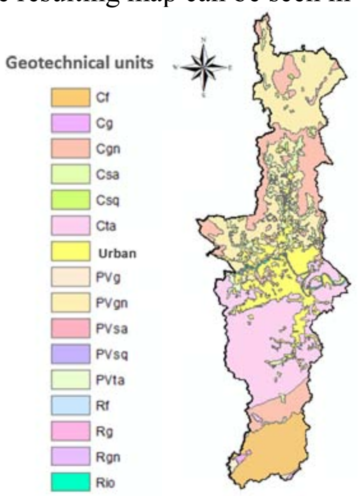

Fig. 4 Geotechnical mapping – Blumenau

Table 2 presents the final relative geotechnical composition of the analyzed region. Its analysis revealed that the classifiable region is represented mainly (circa 50%) by Red-Yellow Podzolic soils gneiss substratum (PVgn) with Cambisols turbidite and a sandstone substratum (Cta)**,** followed by 17.66% Cambisols gneiss substratum (Cgn). Approximately 13% could not undergo geotechnical classification as it was part of the urban area.

Table 2. Geotechnical mapping results

| Geotechnical units | | Area |
|---|---|---|
| PVgn | Red-Yellow Podzolic soils gneiss substratum | 26.14% |
| Cta | Cambisols turbidite and sandstone substratum | 25.24% |
| Cgn | Cambisols gneiss substratum | 17.66% |
| Urban | Urban region | 13.32% |
| Cf | Cambisols phyllite substratum | 10.31% |
| Csa | Cambisols alluvium deposit substratum | 4.64% |
| Rio | Water | 0.77% |
| PVta | Red-Yellow Podzolic soils turbidite and sandstone substratum | 0.51% |
| Csq | Cambisols quaternary deposit substratum | 0.48% |
| PVg | Red-Yellow Podzolic soils granite substratum | 0.35% |
| Cg | Cambisols granite substratum | 0.27% |
| Rg | Litholic soils granite substratum | 0.17% |
| PVsq | Red-Yellow Podzolic soils quaternary deposit substratum | 0.07% |
| Rgn | Litholic soils gnaisse substratum | 0.03% |
| Rf | Litholic soils phyllite substratum | 0.01% |
| PVsa | Red-Yellow Podzolic soils alluvium deposit substratum | 0.01% |

In relation to the geotechnical map allowing other types of analyses, spatial generalizations were carried out by transforming SPT points on surfaces in order to support the preliminary assessment of the land in relation to the works of foundations and other geotechnical applications. Thus, the analysis of admissible stress ($\sigma_a$) in soil was performed with an empirical model. The allowable tension of soil on direct foundation, according to Hachich *et al.* (1998) is defined as:

$\sigma a = 0{,}02.\text{N-value (MPa)}$ (1)

Valid for natural soils with $5 \leq \text{N-value} \leq 20$.

Therefore, $\text{N-value} \geq 20$ was found for the study as a reference limit for direct support foundations. A map of the Blumenau urban area was designed depicting the surface elevation where the admissible stress for direct foundation is greater or equal than 0.4 MPa. A map of surface elevation of the Blumenau urban area was designed will admissible stress for direct foundation equal to 0.4 MPa. Lastly, it was possible to interpolate results related to groundwater level, borehole depth, and admissible stress surface ($\sigma_a$) higher than 0.4 MPa in the urban area of Blumenau with data from the SPT investigation (Fig. 5).

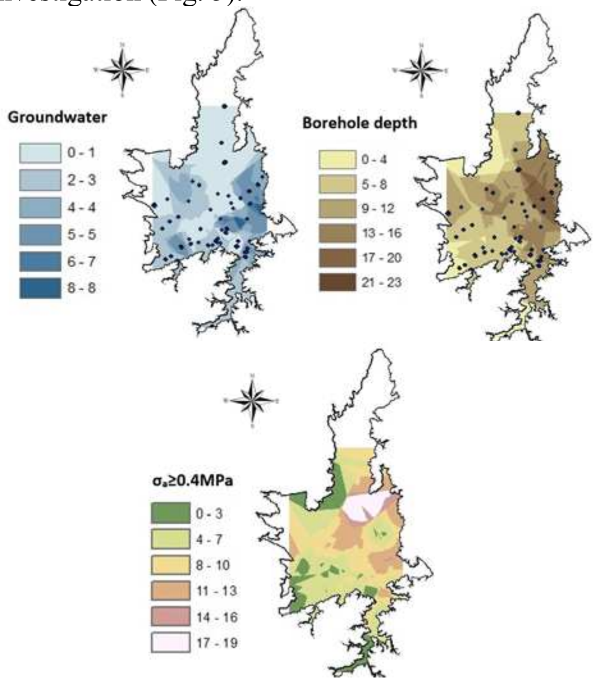


Fig. 5 Maps for groundwater level, borehole depth, and $\sigma_a \geq 0.4$ MPa – Blumenau urban areas

## 4 CONCLUSION AND RECOMMENDATIONS

This paper has briefly presented data collected and utilized in this work in the development of a SIG setting as geotechnical database, as well as analyses performed through specific tools for manipulation of information. In addition to the academic aspect of this study, results are intended as technical subsidies to support decision-making processes of city administrators in the city of Blumenau and other interested parties. The geotechnical database developed allows geographical understanding of geology, lithology, pedology, and declivity, as well as geotechnical mapping, thus informing geotechnical engineering properties of subsurface soils for many uses in the planning and execution of engineering services.

With the declivity map designed for Blumenau it is possible to direct urban growth initially to areas with low (0-6%) and medium (6-15%) declivity, and to areas with high declivity (15-30%) if necessary. Potential restrictions on land subdivision have been proposed by the IPT (1991), as a declivity greater than 30% is considered exceedingly high, which may intensify mass movements.

The geotechnical mapping elaborated provides initial substrate parameters which can aid in soil resistance checking. The evaluation of geotechnical investigation through SPT reports has enabled further improvements to geotechnical mapping. This application allows zoning of a city in favorable areas with different types of foundations, resulting in economic gains in the definition of road deployments, thus making more systematic and rational urban occupation possible.

It should be emphasized that this study may contribute to substantiate land-use planning actions, as well as implementations of civil projects in Blumenau, as it encompasses information regarding the occurrence and special distribution of aspects and parameters in geology, engineering, geomorphology, and pedology. There is also the possibility of further including other aspects in the analyses, such as soil and rock mechanics.

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