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Geotechnical Zoning of the Soils of the Valledupar City Using a GIS

Olga Vanessa Palacio Pacheco, Gustavo Cadena Carrillo, Eberto Rafael Ortega Sinning, Angélica Patricia Vanegas Padilla

Popular University of Cesar, Colombia.

Abstract: The geotechnical zoning of the soils was carried out in Valledupar (Cesar) by collecting data in various soil laboratories and obtaining samples. The research database was created. The types of soils found were SC, SM and GW identified in all the communes of the city. The water table was found at a depth of 1.2 m. The document contains the necessary information for geotechnical studies of the area where it is concluded that the city can support building foundations of more than 10 levels, in areas with high percentages of gravel, and these areas will be the ones with the highest incidence when increasing coverage of aqueduct and sewerage networks. It is the first geotechnical research study through geographic information models in Valledupar, which indicates the generation of a technical and bibliographic resource for quick consultation.

Key words: mapping; geotechnics; types of soils; GIS

1. Introduction

According to the 2005 census, the population of the city of Valledupar was 354,449.0 inhabitants, and projections for the year 2019 are around 493,342.0 inhabitants [1], which shows that there is a significant growth in the population, and has led to a hasty increase in housing construction, road coverage, water and sewage networks throughout the city. Therefore, it is necessary to know how the soils are constituted, since, in order to carry out this type of engineering and infrastructures according to the Colombian standards applicable to each situation, it is necessary to carry out previous studies in the areas to be treated. Therefore, it is necessary to have a tool to help us verify the distribution of soils in the city, thus facilitating decision making [4].

Therefore, it was considered necessary to carry out a geotechnical zoning of the city of Valledupar. In 2017, as a grade project, geotechnical characterization of the subsoil was conducted in the northern part of the capital city of Valledupar. Two samples were collected from 30 apiques in the relevant areas, and the project showcased some of its characteristics. With this information, a database for the city of Valledupar was created, because historically there have been no soil zoning studies that allow for an understanding of its status [12].

A geographic information system (GIS) is a system used to describe and categorize the Earth and other geographies in order to display and analyze the information referred to space [3] and through its use an advanced conceptual model was reached that revealed the geotechnical or geological problems of the soil, which can be used to conduct preliminary studies

for works such as adaptations, amplifications and/or replacements of aqueducts and sewers, among other engineering works [9].

2. Materials and Methods

2.1 Area of study

The research seeks to cover the city of Valledupar, without contemplating the villages, townships and/or the metropolitan area.

2.2 Stage of study

Stage 1: Review of technical information and data collection instruments

Creation of the database: for this purpose, secondary information was collected from different laboratories that carried out studies on the geomechanical characteristics of the soils in the city of Valledupar.

Identification of sampling areas: the points previously collected were located on a map in Google Earth Pro, which facilitated the location of the areas where sampling was carried out.

Identification of sampling points: once the areas were identified, they were visited and, according to their characteristics, easily accessible points were identified for sampling and sample collection.

Field tests: reconnaissance of the areas and sample collection were carried out. Apiques were made at 1-2 m, duplicates of the samples were taken and the following tests were performed:

- ✓ Grain size analysis
- ✓ Soil classification in AASTHO and SUCs
- ✓ Calculation of admissible load capacity
- ✓ Angle of internal friction
- ✓ Determination of liquid limit
- ✓ Determination of plastic limit
- ✓ Determination of shear strength [5].
- ✓ Information such as the water table encountered within the depth range of the piles was included.

Stage 2: Data processing

In this phase, the database was completed with the laboratory results and other information collected, and then processed in a geographic information system using the IDW interpolation method. This resulted in the elaboration of the geotechnical representation of the soils [7].

Stage 3: Analysis and discussion of results

The geotechnical areas were analyzed according to land use based on the necessary requirements for the preliminary studies requested by the Technical Regulations of the Drinking Water and Basic Sanitation Sector, showing the most relevant characteristics of the communes including the identification of soil types, depth of the water table, and others. [6].

2.3 Results

2.3.1 Soil classification of the city of Valledupar is using the unified soil classification system (Sistema Unificado de clasificación de Suelos - SUCs)

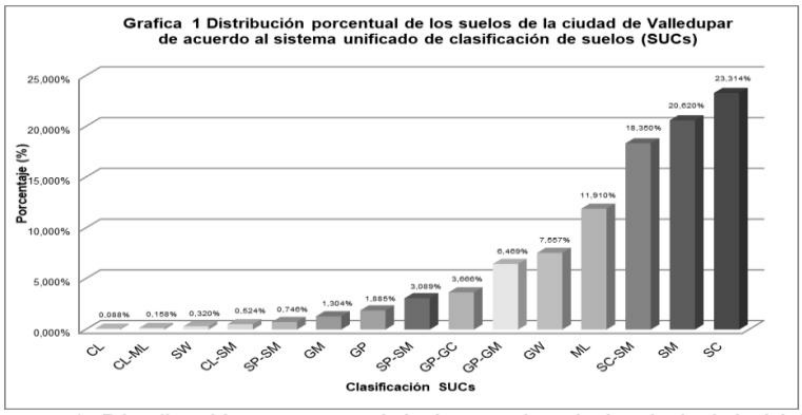
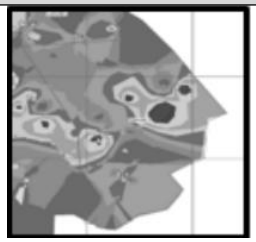
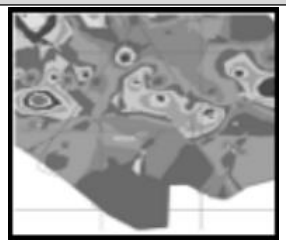
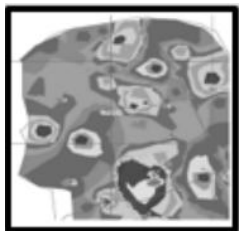
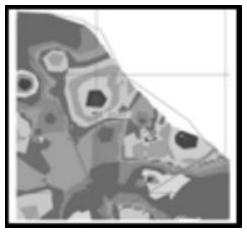


Figure 1. Percentage distribution of soils in the city of Valledupar according to the unified soil classification system (Sistema Unificado de clasificación de Suelos - SUCs).

According to the classification of the unified soil classification system [4], the study area is 5089.593 hectares, of which a SC type soil predominates (poorly graded sand, sand with gravel, mixture of little or no fine/silt, mixture of sand and silt), accounting for 23.314% of the study area, and corresponding to 1186.5752 hectares compared with the total surface area.

The city of Valledupar is distributed in 6 communes, which are taken into account in the development of the project, so the interpretation of the results was carried out accordingly:

Table 1. Communes distribution of the city of Valledupar's soils according to the unified soil classification system (SUCs)

Commune 1	Commune 2	Commune 3
		
This is the smallest area where well graded gravel soil, gravel and sand mixtures, with little or no fine particles, are found, and this type of soil has the highest quantity.	Various soils have been discovered, such as SC-SM and SM (silty sands, mixed sand and silt).	Most of the soil type in the commune is SM, whose mechanical properties range from acceptable to good, and drainage capacity from acceptable to poor.
Commune 4	**Commune 5**	**Commune 6**
		
It has a high proportion of SC soil type, poor mechanical properties to acceptable, and poor drainage capacity to impermeable.	There are more than 5 construction projects in the commune, and the SC soil type with poor mechanical properties is acceptable.	various soils with very special characteristics have been showed, such as SM, GP-GC.

2.3.2 Soil typification of the city of Valledupar by the American Association of State Highway Officials (AASTHO)

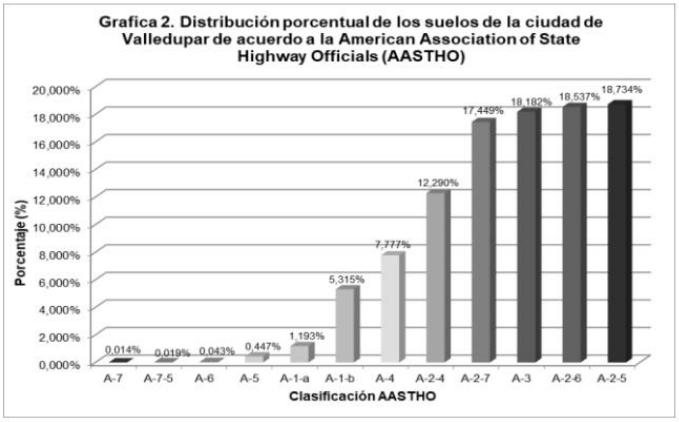
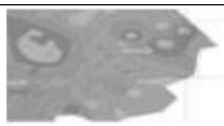
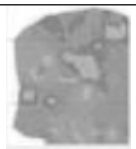


Figure 2. Percentage distribution of soils in the city of Valledupar according to the American Association of State Highway Officials (AASTHO).

In the city of Valledupar, A-7 type soil can be found, covering an area of 0.7125 hectares, while the total study area is 5089.593 hectares. This type of soil is the least commonly found in the region, and at the same time, A-2-5 type soil accounts for the majority in this 953.474 hectares study area. The following table lists the area of each type of soil found in the city according to this classification.

Table 2. Distribution by communes of soils in the city of Valledupar according to the American Association of State Highway Officials (AASTHO).

Commune	Description
	In commune 1, there are A-2 and A-3 groups of soil, representing fine sand, shells, silt, and clay sand. Most of its areas have A-2-4, A-2-6, and A-2-5 types of soil.
	In commune 2, most of the area has soils of group A-2 gravel and silty or clayey sands, A-3 fine sands, and A-4 silty soils, as well as subgroups A-2-7, A-2-6.
	In commune 3, A-2-5, A-2-4, A-2-6 are found in most of the area of this commune, and A-4 and A-5, which are silty soils, are found in a minority of the area.
	In commune 4, most areas of commune are covered A-2-5, and the A-4 type soil is silt, with a relatively small proportion.
	In commune 5, we find soils of type A-2-4, A-2-6 and A-3. The proportion of A-1-a type soil is relatively low.
	In commune 6, there are soils of type A-1-a and A-1-b that represent the group of coarse granular soils with gravels and sands, and subgroups A-2-4, A-2-5 and A-2-6 that belong to the granular group with presence of gravels and silty clayey sands.

2.3.3 Depth of the water table in the city of Valledupar

Valledupar is one of the cities with large amounts of groundwater, so it has soils with good drainage capacities and permeability in the subsoil, carrying rainwater to recharge areas, so the water table can be found at depths of 1.2 m in neighborhoods such as Garupal (commune 5).

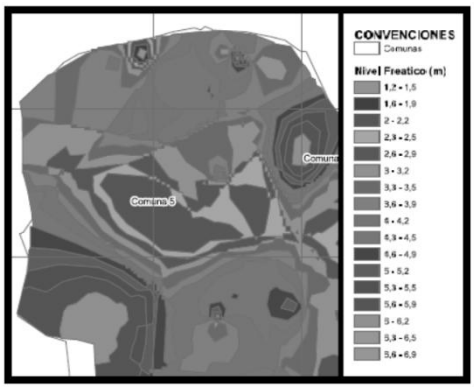


Figure 3. Water table: commune 5.

2.3.4 Percentage of natural moisture in the soil of the city of Valledupar

In general, it was found that natural soil moisture ranges from 6.3-11.8%. In commune 2, it can be observed that the range of 0.9 to 6.2% predominates. This is the lowest range found.

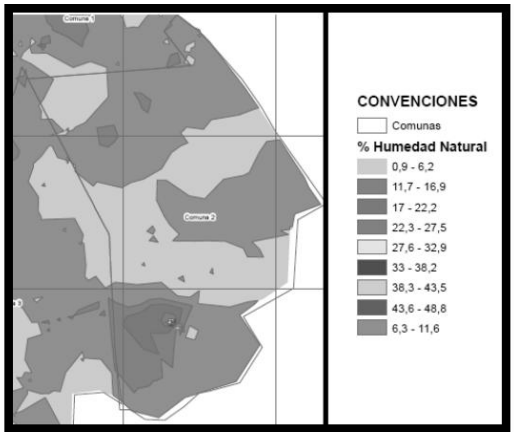


Figure 4. Natural humidity: commune 2.

2.3.5 Plasticity index

Commune 4 is the one with the greatest variability, showing ranges from 0-2.5 to 10.2-12.6. This indicates that this commune has greater compressibility than the others.

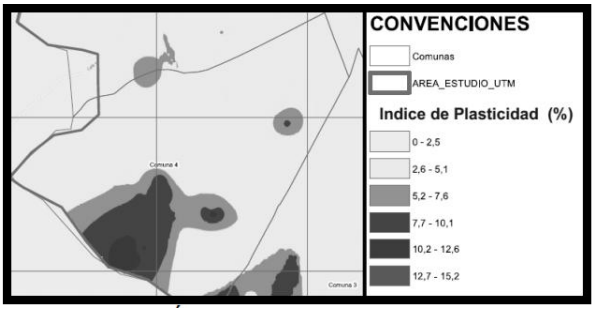


Figure 5. Plasticity index: commune 4.

2.3.6 Load capacity

For the analysis of this item, the depth and the ranges with greater and lower presence according to the area covered by each one were taken into consideration [8].

Table 3. Load capacity

Depth	Ranges with greater presence	Ranges with lower presence
50 cm	8.1-9.1	13.8-14.9
100 cm	10.2-12.1	22.1-23.9
150 cm	14.2-16.3 16.4-18.5	25.3-27.4
200 cm	20.3-22.9	33.7-36.2
250 cm	22.3-26.0	45.1-48.0
300 cm	29.6-32.2	51.1-56.4
350 cm	27.1-32.2	74.9-95.4
400 cm	35.5-36.9	72.0-114.8

2.3.7 Angle of internal friction.

In general, it can be observed in a range of 31-32°, however, in the central part of commune 4 (La Victoria, Populandia, Villa Miriam Francisco de Paula) it varies from 32 to 38° and in the southern part of commune 4 (Ciudadela 450 years, San Geronimo and Girasoles), its variation range is 29-30°.

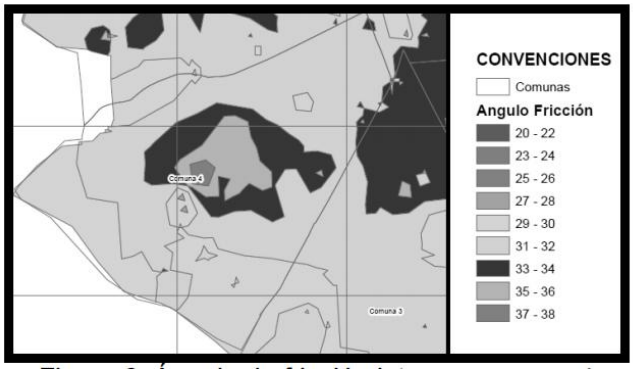
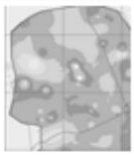


Figure 6. Angle of internal friction: commune 4.

2.3.8 Standard penetration test (SPT)

The standard penetration test is used to make a geotechnical survey of soils, since it allows characterizing granular soils (sand and sandy gravels), as well as in clay soils to know the natural moisture of the soil [11].

Table 4. Standard penetration test (SPT)

Commune	Description
	Commune 1: Significant variations are presented from 3-6 to 30-32.
	Commune 2: It shows a range of 20-22 in most of its area, with some ares showing a range of 17-19.
	Commune 3: In this commune, values of 17-19 predominate, although in the northern part of the commune, there are small areas with values of 30-32.
	Commune 4: The value for the northern part of the commune is 20-22, while the value for the southern part is 17-19.
	Commune 5: A great variation of the ranges is observed, although the range of 20-22 has a great preponderance.
	Commune 6: The range of 20-22 is predominant, although values of 26-29 and 30-32 are also observed.

2.3.9 Winkler model

From the map, it can be seen that the range of 1.061-1.233 and 1.234-1.406 is dominant, while the range of 1.924-2.096 is smaller.

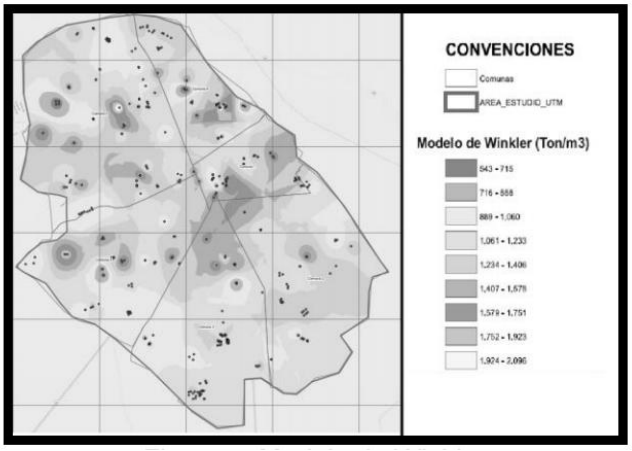


Figure 7. Winkler model.

2.3.10 Shear wave velocity

The shear wave velocity is related to the stiffness and density of the ground through which it is propagated, so it is a geophysical parameter used to know the seismic response of the studied soils [11]. All communes have evidence indicating that the common shear wave velocity is 233-245 m/s.

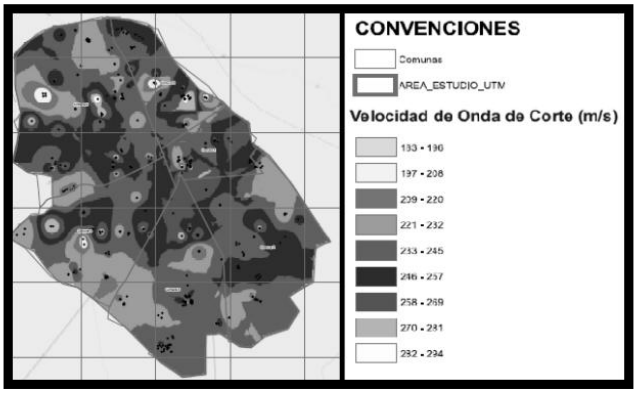


Figure 8. Shear wave velocity.

3. Discussion (or Analysis of Results)

With the zoning results, it was observed that sandy and gravel soils are predominant in the city. In terms of load capacity, from 0.5 m to 4 m depth (depths studied), there is a gradual increase due to the increase in depth. It is defined that the city can support foundations for buildings of more than 10 levels with a load capacity of more than 50 ton/m^2 at 4 m, in areas with high percentages of gravel. These areas will have the greatest impact when it comes to increasing the coverage of water and sewerage networks, so the present studies will help to observe more clearly the conditions of the areas to be treated.

Most of the study area is urbanized and those that are not, are planned for future construction, so this work can be of help as a preliminary study.

With the inclusion of the studies in the realization of the geographic information system, it was possible to verify that the city is rich in groundwater by being able to find a low water table at a depth of 1.2 m. It is also worth noting the fact that the water table could be found in most of the studies used for the database for zoning.

4. Conclusion

In the area studied in the city of Valledupar, SC, GW, ML, GP-GM, SP-SM, SM and SC-SM soils were found in the higher percentage. These soils are used for the construction due to their characteristics, as they contain a high proportion of gravel, sand, and clay combinations, with high bearing capacity and excellent mechanical properties.

Considering the depth of the urban groundwater level, some areas have groundwater levels below 2 m. It is best to avoid the construction of high-rise buildings, as well as aqueduct and sewer structures such as inspection wells, elevated water tanks, and rainwater sewers in these areas, which have the highest incidence in communes 1 and 5 near the Guatapurí River.

This geotechnical zoning is used as a reference for previous (preliminary) studies of infrastructure projects such as water supply and sewer networks, because the map fully meets the prerequisites for soil studies of RAS drinking water and basic sanitation projects, in which soil classification, permeability, groundwater level and other data need to be determined.

Research is also useful in other areas of knowledge such as civil engineering, architecture and sanitary engineering, since it allows us to know the environmental conditions of the environment in which we wish to work before carrying out

an intervention.

The information of this project is the basis for executing similar projects or updating maps that have already been drawn. It is recommended to create an application as a tool to enable students to incorporate new information into the database, which is collected in the field, can expand and unify urban soil information, and make it easy for future researchers and/or university communities to access.

Acknowledgments

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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