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Prediction of the soil-water characteristic curve of Brazilian soils using general-purpose pedotransfer functions

Fernando Carolino da Silva[1#], José Camapum de Carvalho[2], Gilson de F. N. Gitirana Jr.[3], Isabela Cristina Mesquita Machado[3], Renato Marques Cabral[4]

Article

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Abstract

Several predictive models have been proposed in the literature to estimate soil-water characteristic curves (SWCCs) using basic soil properties. However, most of these models were not originally calibrated for tropical soils, such as bimodal materials commonly found in Brazil. To assess the applicability of some of these models to Brazilian tropical soils, which often present fine-particle cementation and lateritic behavior, this study evaluates four physico-empirical approaches: Arya & Paris (1981), Arya & Dierolf (1989), Aubertin et al. (2003), and Wang et al. (2017). A database containing information on 95 Brazilian soils was compiled and used as the basis for the analysis. The results showed that, in their original form, none of the evaluated models consistently represented the SWCCs of these soils with sufficient accuracy. Due to the models' poor performance, specific geotechnical concepts not incorporated in the original formulations were examined and found to significantly influence the predictions. This analysis revealed that the Arya & Paris (1981) model holds promising potential for estimating the SWCC, provided that particle aggregation is addressed by combining grain-size distributions obtained under different dispersion states. Accordingly, this article proposes guidelines for the enhanced application of the Arya & Paris (1981) model in Brazilian geotechnical contexts, with the aim of improving predictive accuracy and broadening its applicability.

1. Introduction

In tropical regions, such as Brazil, soils predominantly exhibit unsaturated conditions which strongly affect their geotechnical behavior and make the exclusive use of classical saturated soil mechanics concepts inadequate (Camapum de Carvalho et al., 2015). Unsaturated soils require the application of unsaturated soil mechanics principles, with the soil-water characteristic curve (SWCC) playing a central role in interpreting the relationships among water content, suction, and hydro-mechanical properties (Fredlund et al., 2012). In this context, interpreting and modeling the SWCC involves numerous variables, including the initial water content and density, stress history, temperature, salt content, and soil structure (Li et al., 2014).

Although accurate and preferred, direct experimental methods for determining the SWCC are laborious and time-consuming, thereby encouraging the use of predictive models – statistical, empirical, and physico-empirical. These predictive models, also known as pedotransfer functions, allow the estimation of the SWCC using basic soil properties, such as the soil porosity and the grain-size distribution (GSD). However, the applicability of general-purpose models (e.g., Arya & Paris, 1981; Aubertin et al., 2003) to tropical materials is questioned due to their calibration with data from other regions (Silva, 2022). Despite the recent development of pedotransfer functions specifically tailored to bimodal lateritic soils of tropical regions (e.g., Santos Pereira et al., 2024; Alves et al., 2025, 2026), evaluating general-purpose models remains relevant because of their widespread use.

The analysis of soils in tropical climate regions and the development of pedotransfer functions for these materials require the adoption of specific concepts for highly structured unsaturated soils. It is essential to account for the particularities of these materials in terms of physical, chemical-mineralogical, and structural properties, as well as the effects of compaction or pre-consolidation, all of which are directly related to soil porosity. In addition, according to Camapum de Carvalho & Gitirana Junior (2021) and Gitirana Junior et al. (2025), the study and analysis of the properties and behavior of tropical

#Corresponding author. E-mail address: fernandocarolinodasilva@hotmail.com
[1]The Mosaic Company Brazil, Catalão, GO, Brasil.
[2]Universidade de Brasília, Faculdade de Tecnologia, Brasília, DF, Brasil.
[3]Universidade Federal de Goiás, Escola de Engenharia Civil e Ambiental, Goiânia, GO, Brasil.
[4]Universidade Estadual de Goiás, Eletrobrás Furnas, Anápolis, GO, Brasil.

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soils require the consideration of macro and micro porosity and effective water content, as these are the parameters that define the soil's hydro-mechanical behavior. The definition of macro and micro porosity and water content depends on microstructural aspects, such as particle aggregation (Roseno & Camapum de Carvalho, 2007).

The primary objective of this study was to evaluate the performance of physico-empirical models in predicting the SWCC of Brazilian tropical soils. Four models, some of which are widely cited and used, were analyzed: Arya & Paris (1981), Arya & Dierolf (1989), Aubertin et al. (2003), and Wang et al. (2017). For this purpose, a database was compiled that includes experimentally determined SWCCs, grain-size distribution curves, and soil physical and chemical properties. The SWCCs predicted by the models were compared with directly determined laboratory data using as statistical metrics the coefficient of determination (R^2) and the root mean squared error (*RMSE*). Close attention was paid to the performance of the models when applied to soils exhibiting bimodal behavior. The analysis of deviations between predicted and directly measured SWCCs supported the proposal of model adjustments aimed at enhancing their applicability to tropical soils.

2. Theory and pedotransfer modeling fundamentals

There are several approaches available for the development of pedotransfer functions, such as regression analysis, pore-scale and fractal modeling, and the use of machine learning (Santos Pereira et al., 2025). Most models rely on simple soil parameters as input variables but greatly vary in terms of theoretical complexity and size of the database used for calibration. Currently, the family of models developed by Santos Pereira et al. (2026) can be considered to be the most general, since they were based on the largest database used for this purpose. However, older and simpler pedotransfer models remain widely used, despite their potential limitations and small calibration databases. The present study evaluates the effectiveness of four of these models to estimate the SWCC of tropical soils. The models analyzed are those proposed by Arya & Paris (1981), Arya & Dierolf (1989), Aubertin et al. (2003), and Wang et al. (2017). The fundamentals and theories behind these models are presented in the next sections.

2.1 Arya & Paris (1981) model

Arya & Paris (1981) proposed the first well-known physico-empirical method for estimating the SWCC, using information from the grain-size distribution curve, bulk density, and particle density. The model is based on the observed similarity between the GSD and the SWCC, although this relationship may be influenced by the methodology used to determine the GSD, an issue that will be addressed throughout this article. The model translates the GSD into a pore-size distribution, including the pore volume and representative pore radius associated with each grain-size fraction. For this, the GSD curve is divided into *n* fractions, each presenting an idealized water retention curve defined by an air-entry value computed using Laplace's capillarity equation and assuming abrupt drainage. The soil's fractions are drained according to their pore-size, from larger to smaller.

Arya & Paris (1981) included an empirical parameter, α, to account for the non-sphericity of particles. The empirical parameter α, a key component of the model, was evaluated for different soils, yielding values between 1.150 and 1.459, with an average value of 1.38 for their database. Arya & Paris (1981) suggest the following specific values of α, according to USDA soil classes: 1.285 for Sa; 1.459 for Sa-L; 1.375 for L; 1.150 for Si-L; and 1.160 for C.

Later, Arya et al. (1999) redefined α as an indirect function of the grain-size, instead of a constant value, in an attempt to better represent the different textures of the analyzed soils. This modification was not considered in the present work. The general framework introduced by Arya & Paris (1981) serves as the basis for several other pedotransfer functions and, for that reason, was selected for the current study. It is important to note, however, that it does not consider several water retention mechanisms, such as water adsorption.

2.2 Arya & Dierolf (1989) model

The SWCC pedotransfer function proposed by Arya & Dierolf (1989) revises the earlier formulation by Arya & Paris (1981) by modifying its empirical parameter, α. The α parameter was replaced by a newly defined constant, called α^*, which represents the effective length of the pores associated with each soil fraction. The α^* parameter was evaluated based on the experimental data from Arya & Paris (1981), yielding values between 0.3 and 1.5 cm, corresponding to the wetting and drying ranges of SWCCs for soils of varying textures. An average value of 1.0 cm was suggested. The greatest advantage of the Arya & Dierolf (1989) modified model is being less sensitive to the α^* parameter.

2.3 Aubertin et al. (2003) model

Aubertin et al. (2003) proposed a set of equations to predict the SWCC, modifying the original model by Kovács (1981) to clearly define its input parameters and extend its applicability to fine- and coarse-grained soils. The model assumes that water retention results from the combined effects of capillarity and adhesive forces. Similar to previous models, the approach was developed for isotropic and homogeneous materials under drying conditions and does not consider factors such as anisotropy, internal microstructures, presence of aggregations, or volume changes.

The model uses several input parameters. The GSD is represented in terms of a distribution parameter, *m*, the diameter of the particle for which 10% of the total sample is smaller, D_{10}, and the coefficient of uniformity, C_U. Adsorption in fine-grained materials is represented using the adhesion coefficient, a_c, and a correlation with the liquid limit, w_L. The Aubertin et al. (2003) model offers a flexible approach that presents potential applicability to tropical soils, since it combines the properties of the coarse pores present in tropical soils and the properties of their fine-grained fraction.

2.4 Wang et al. (2017) model

The method proposed by Wang et al. (2017) for predicting the SWCC assumes spherical particles and cylindrical pores and is tailored specifically for coarse-grain materials. The model offers equations for the prediction of the van Genuchten (1980) model parameters *a* and *n*. The parameter *m* is fixed as a function of *n*, using Mualem's hypothesis. The pedotransfer function expresses the SWCC in terms of the effective degree of saturation and does not provide an estimation of the residual water content and of the residual zone.

To establish equations for *a* and *n*, the authors employ dimensional analysis, obtaining elegant regression equations based on the diameter of the particle for which 60% of the total sample is smaller, D_{60}, and the coefficient of uniformity, C_U. These parameters are evaluated under two idealized scenarios: (i) uniformly graded particles, where pores exhibit a narrow distribution, resulting in a steep SWCC ($C_U = 1$ and $n \rightarrow \infty$); and (ii) highly well-graded (polydisperse) particles, where fine particles fill the pore spaces, impeding desaturation and leading to a gently sloping SWCC ($C_U \rightarrow \infty$ and $n \rightarrow 1$). These scenarios define the limiting values of parameter *n*. The equations proposed by Wang et al. (2017) are simple and provide reasonable predictions for sands. Its potential applicability to fine-grained tropical soils should not be disregarded due to the fact that these tropical materials often present large pores formed by pedogenetic processes and low fine-fraction activity.

3. Materials and methods

3.1 General approach

The present study was based on three main pillars: (1) selection of data published in Brazilian theses and dissertations on unsaturated soils; (2) careful homogenization of the database, reprocessing of GSD curves using the fitting model by Fredlund et al. (2000) and of SWCCs using the Gitirana Junior & Fredlund (2004) fitting equation; and (3) evaluation of the predictive performance of SWCC models by comparing experimental and estimated data using the coefficient of determination, R^2 and the root mean squared error, *RMSE*.

The establishment of the values for the empirical parameter α from Arya & Paris (1981) was done according to the soil texture and suggested values by the original authors. The application of the models by Aubertin et al. (2003) and Wang et al. (2017) required the extrapolation of some missing D_{10} values using the Fredlund et al. (2000) equation and limiting the minimum particle diameter to 0.0001 mm, corresponding to the clay fraction in the USDA (1999) classification. Further considerations on these assumptions can be found in Silva (2022).

3.2 Database

Data collection encompassed three regions of Brazil: South, Southeast, and Center-West. A total of 95 datasets were gathered, representing soils with different physical and morphological characteristics, textural classes, and mineralogical composition. Of these datasets, 62 correspond to undisturbed soils and 33 to compacted soils. Each dataset includes values for specific particle weight, liquid and plastic limits, and void ratio. Additionally, the datasets contain GSDs determined both with and without the use of a deflocculant, as well as well-defined experimental SWCCs.

Most SWCCs in the database were determined using a hybrid/mixed path (39), in which wetting and drying data points are combined into a single curve, both starting typically from either natural or compacted water contents. The database also includes SWCCs determined through the wetting path (37 datasets) and the drying path (19 datasets). The database also includes two study sites that employed non-conventional methodologies for determining GSD curves, referred to as "Special Granulometries." These sites are located at the Experimental Campus of the University of Brasília (DF) and the Furnas Experimental Campus in Aparecida de Goiânia (GO). A detailed description of each evaluated material can be found in the study presented in Silva (2022).

3.3 Database presentation

The following section presents a summary of the information related to GSD, the textural triangle, and the experimental SWCCs in the database analyzed.

3.3.1 Basic physical properties

Figure 1 shows the GSDs of the complete database. Figure 2 presents the textural triangle along with the classification results, incorporating data obtained both with and without deflocculant. Additional plots, organized by Brazilian regions, are available in the study presented by Silva (2022). Figures 1 and 2 highlight the significant variability in the GSDs of tropical soils, as well as the influence of the use of deflocculant in the determination of the GSD curves. The developed database is significantly variable, as expected when collecting data of representative soils from large regions. This variability highlights the difficulty in developing a predictive model capable of adequately representing the SWCC in a comprehensive manner.

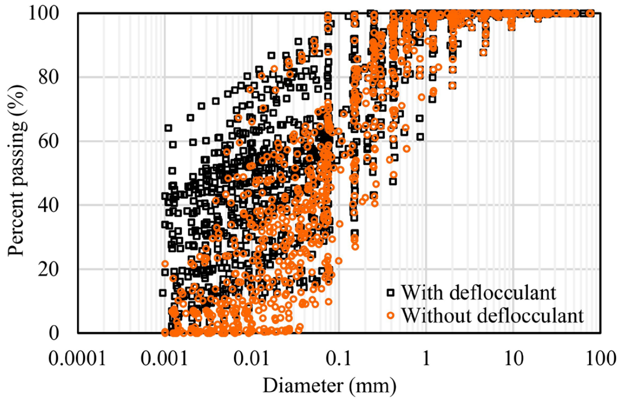

Figure 1. Grain-size distributions.

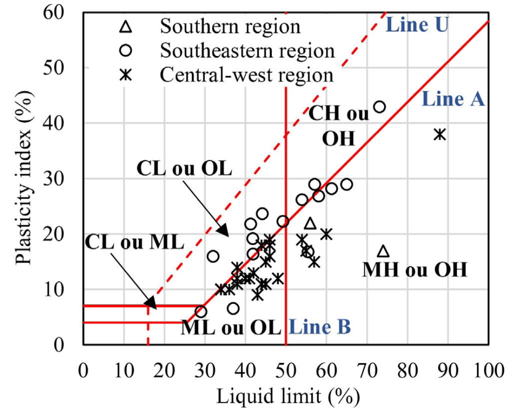

Figure 3. Plasticity chart.

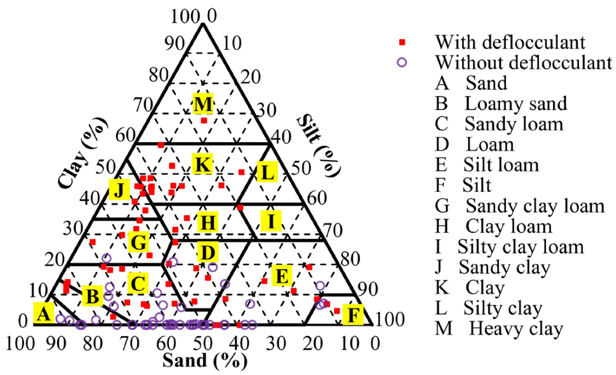

Figure 2. Textural triangle considering grain-size distribution curves with and without defloculant.

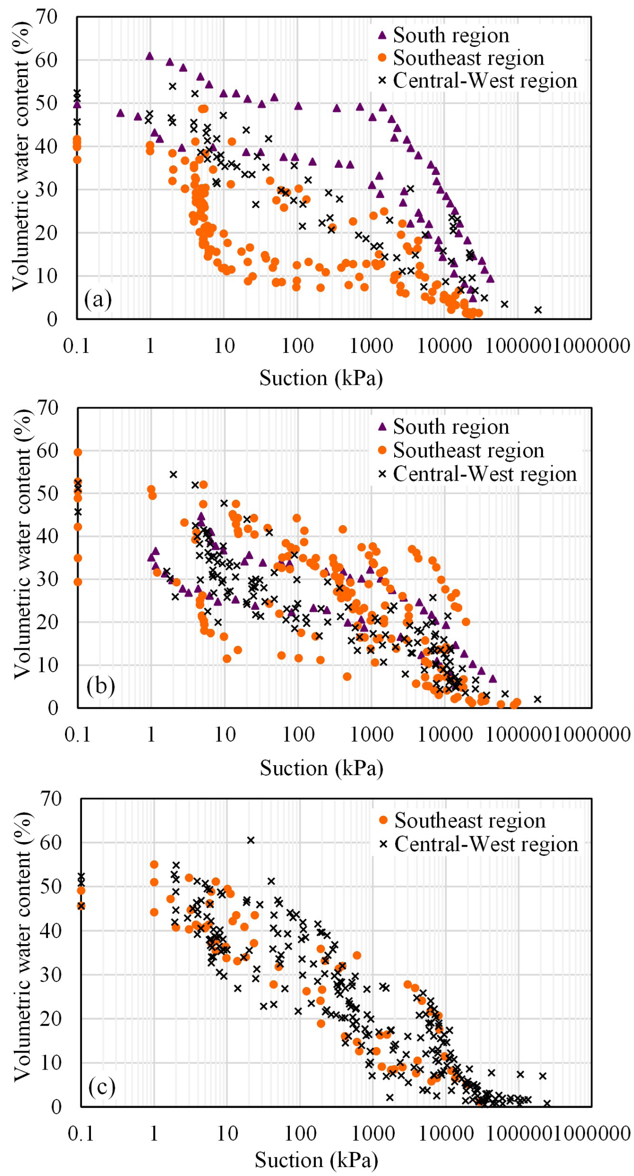

Figure 4. SWCCs of undisturbed samples: a) drying curves; b) wetting curves; c) hybrid/mixed curves.

It is important to observe that the extrapolation of the curves down to a minimum particle diameter of 0.0001 mm was necessary due to the lack of data in that range. Some of the pedotransfer functions require D_{10} values that could only be estimated through such extrapolation. It is important to note that extrapolations, when needed, often involved GSDs obtained with the use of defloculant. The corresponding GDSs obtained without defloculant are significantly coarser, a typical feature of tropical soils that present fine particle aggregations that are stable when in contact with water.

Figure 3 shows that most of the data is concentrated in the ML (low compressibility inorganic silts), OL (medium compressibility inorganic silts and organic silts), and MH or OH (high compressibility inorganic silts and organic clays) regions. Only a small amount of data is found in the CL and CH regions (low and high compressibility inorganic clays, respectively).

3.3.2 Soil-water characteristic curves

Figures 4 and 5 present the experimental SWCCs that are included in the database. It can be observed that the range of suction required to desaturate the soil is broad.

Most soils exhibit bimodal behavior, characterized by two pore-size families. The first pore-size range, referred to here as macropores, can be drained with suction values generally between 1 and 10 kPa. The second pore-size family, called mesopores, corresponds to pores that are drained when suction in the approximate range of 10 to 10,000 kPa is applied. Micropores are those pores that are so small that they can only drain when suction values greater than about 10,000 kPa are applied. All these suction values are indicative rather than absolute, as the exact values depend on the specific soil. This implies that the definitions of macro-, meso-, and micropores are comparative and not strictly determined by fixed suction values or pore sizes.

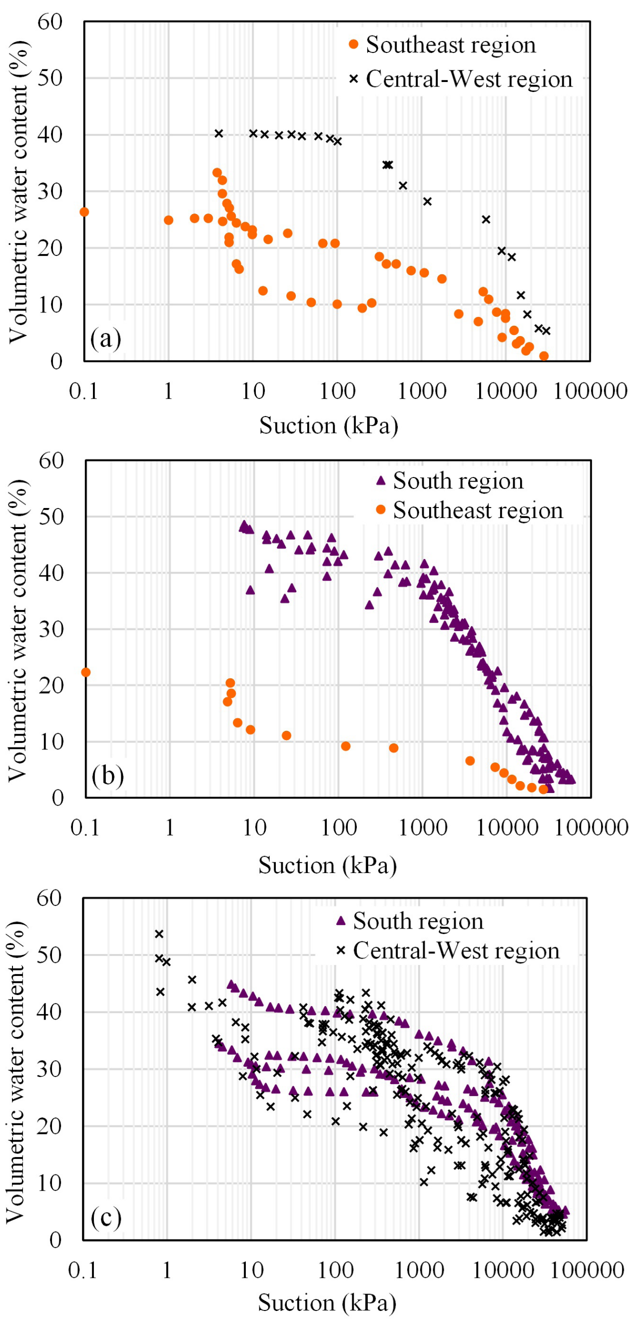

Figure 5. SWCC of compacted samples: a) drying curves; b) wetting curves; and c) hybrid/mixed curves.

The data shown in Figures 4 and 5 reveals the degree of variability of key parameters, such as the air-entry values of macro- and micropores, the bimodal and unimodal shapes of the curves, and the variations in the saturated volumetric water content. In general, data variability is primarily concentrated in the macro- and mesopore regions, while in the micropore region, beyond 10,000 kPa, the SWCCs are more similar. This observation is significant because it suggests that the range of variation of the air-entry values in the micropores is narrow, indication that the development of a predictive model focused on the macro- and mesopore regions presents a greater challenge.

4. Presentation and analysis of results

Considering the extent and complexity of the data used in the predictions, and with the aim of optimizing the interpretation of the results, this section is organized into two distinct topics. The first presents a global evaluation of the pedotransfer functions, analyzing their efficiency in predicting the SWCCs of tropical soils. The second provides an assessment of the feasibility of applying the Arya & Paris (1981) model to tropical soils, as well as potential adaptations to address their specific characteristics.

4.1 General evaluation of pedotransfer functions

Figure 6 presents the results obtained from applying the pedotransfer models to four selected representative soil datasets extracted from the database. Prediction results for all materials are available in the study by Silva (2022). The performance of the pedotransfer functions was inconsistent, with varying degrees of adherence to directly measured data.

The air-entry values of the macropores were poorly estimated for all four soils; however, better predictions were obtained using the Arya & Paris (1981) model with the dispersed GSD and the Aubertin et al. (2003) model for coarse-grained materials. The steepness of SWCCs was predicted successfully for most materials, indicating that the relationship between the uniformity of the GSDs and the SWCC drainage slope is adequately represented by the models. The prediction of the volumetric water content corresponding to the microporosity of bimodal soils (i.e., the coordinate of the nearly horizontal mid-portion of the SWCCs) was successful for only a small fraction of the datasets. Finally, the micropore drainage region was probably the most difficult to predict, in part because the corresponding pore sizes lie beyond the reach of the available GSD information.

For the global evaluation of the predictive models, considering all 95 datasets, two statistical parameters were employed: the coefficient of determination (R^2) and the root mean square error (RMSE). The R^2 and *RMSE* values were computed using water content values at the same suction. R^2 values close to 1 and *RMSE* values close to 0 indicate good performance in predicting the SWCC. Table 1 presents the global average values of the R^2 and *RMSE* parameters, segmented by model type and soil condition. The analysis of these results indicates that the models are not well suited for tropical soils. The different trajectories (mixed, drying, and wetting) used to determine the experimental SWCC were evaluated separately, and in none of them were the predictive models able to produce adequate predictions of the SWCC.

In summary, the results indicate that the predictive models exhibit erratic performance when used on tropical soils, whether in undisturbed or compacted samples. Overall, the determination of the most suitable predictive model is not possible. It is also not possible to indicate which regions of the SWCC (i.e., macro-, meso-, or micropore zones) are

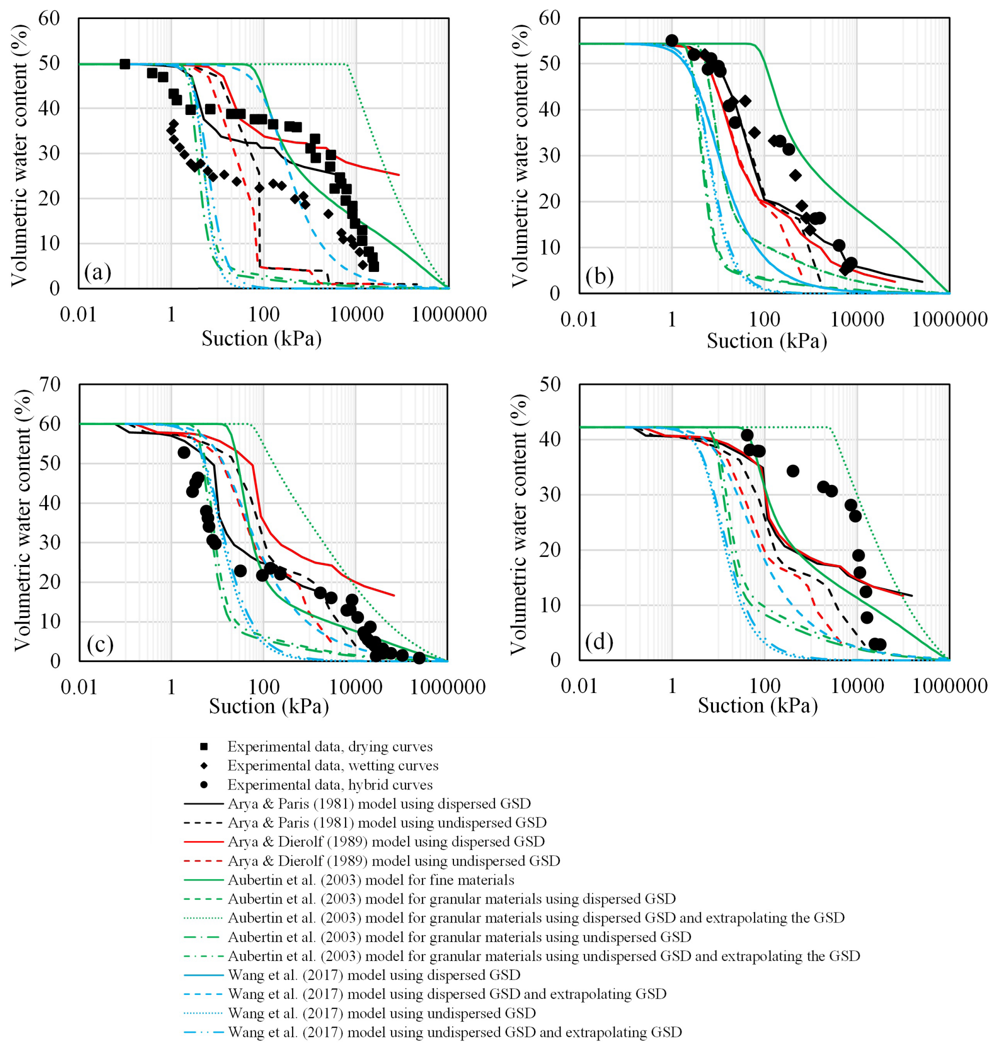

Figure 6. SWCC predictions: a) Timbé do Sul (SC), undisturbed; b) Tinguá (RJ), undisturbed, (c) Brasília (DF), undisturbed; and d) Brasília (DF), compacted.

Table 1. Average performance of the pedotransfer functions for 95 soil datasets.

Model	Soil condition	Global average R^2	Global average *RMSE*
Arya & Paris (1981)	Undisturbed	-0.297	0.106
	Compacted	-0.194	0.107
Arya & Dierolf (1989)	Undisturbed	-0.355	0.107
	Compacted	-0.036	0.099
Aubertin et al. (2003)	Undisturbed	-1.267	0.143
	Compacted	-0.539	0.112
Wang et al. (2017)	Undisturbed	-1.688	0.164
	Compacted	-1.470	0.157

better represented by the models. In some cases, the models exhibited good predictive capacity, while in others they showed significant deviations, both underestimating and overestimating the directly measured water contents and/or suctions. In certain instances, discrepancies in terms of soil suction of one or two orders of magnitude were observed. Therefore, using these models in their original form may yield predictions that substantially diverge from the experimental data. In specific cases, as indicated in the interpretation of Figure 6, some aspects of the predictions were partially satisfactory, suggesting that further investigation and model calibration could lead to suitable predictions for tropical soils.

4.2 Proposal for adapting the Arya & Paris (1981) model to tropical soils with particle aggregates

The grain-size distribution (GSD) is the primary property used in SWCC pedotransfer functions, including the Arya & Paris (1981) model. However, the GSD of some tropical soils can vary considerably, depending on the method of particle-size analysis and sample preparation. This variability arises mainly because fine particle aggregations are commonly present in these soils (Roseno & Camapum de Carvalho, 2007). Such aggregations exhibit different degrees of resistance to dispersion techniques, such as the use of deflocculant and ultrasound. Moreover, the degree of particle aggregation provides valuable information about pore sizes (Alves et al., 2025). Consequently, analyzing the sensitivity of model predictions to variations in GSD can reveal both the limitations and the potential of the pedotransfer model. Pedotransfer functions can potentially be adapted to tropical soils by selecting the most appropriate GSD determination conditions that are representative of the soil in the field.

Figures 7 and 8 present the GSDs of soils from the Brazilian cities of Brasilia (DF) and Aparecida de Goiânia (G), respectively. The analyses were carried out using different methodologies. Laser granulometry (LG) was carried out with and without deflocculant (D, nD) and with and without ultrasound (U, nU). Conventional particle-size analysis using hydrometer and sieving methods (CG) was done with and without deflocculant (D, nD). In addition, samples were prepared under different conditions, such as maintaining the natural water content (Nwc), air-drying (ADwc), and oven-drying (ODwc). These identifiers were used in the legends of the figures.

Roseno & Camapum de Carvalho (2007) observed that greater degrees of weathering of tropical soils – often associated with shallower materials – increase the need

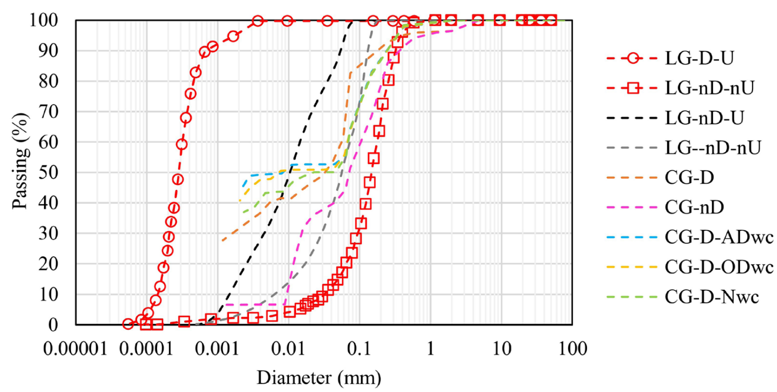

Figure 7. Grain-size distributions of a collapsible clay from Brasilia (DF), 2 m depth (data from Silva, 2007; Restrepo, 2010; Lopera, 2016).

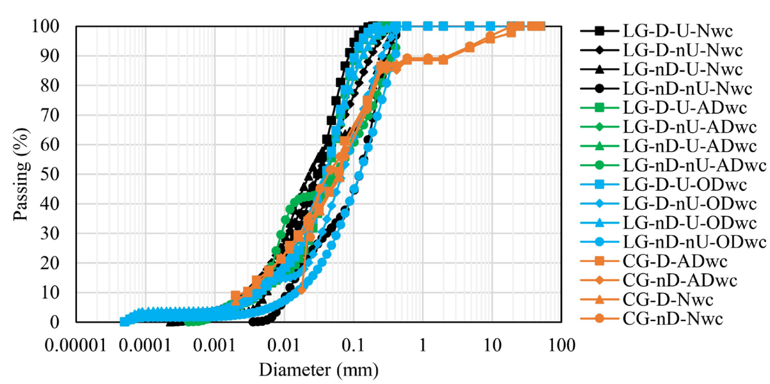

Figure 8. Grain-size distributions of a residual soil from Aparecida de Goiânia (GO), 4.7 m depth (data from Borges, 2010).

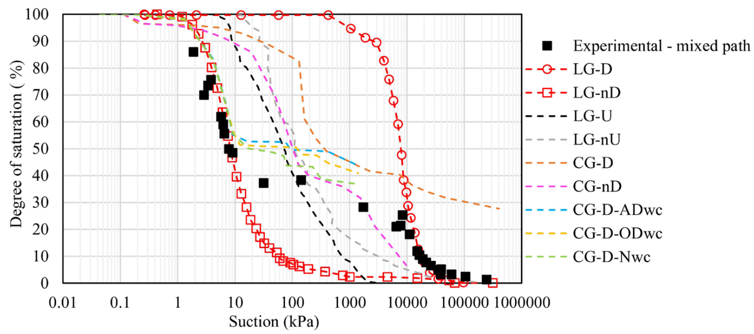

Figure 9. Prediction of the SWCC of the soil from Brasília (DF) using the Arya & Paris (1981) model.

for both chemical deflocculants and ultrasound to achieve complete particle disaggregation. This behavior is evident in the results shown in Figures 7 and 8. Figure 7 clearly demonstrates that when the laser granulometry method is applied without defloccullant and without ultrasound, soil aggregations remain more stable, leading to a coarser GSD. In contrast, when laser granulometry is performed with both a defloccullant and ultrasound, significant disaggregation of the material occurs. The soil from Figure 8 demonstrated the same behavior, but with a smaller difference between the GSDs. This is due to the fact that this soil was collected from a depth of 4.7 m and presents a lower degree of weathering and lower quantity of particle aggregates.

To assess how the methodology used for determining the GSD affects SWCC predictions, all GSDs presented in Figures 7 and 8 were applied to the Arya & Paris (1981) model. This pedotransfer function was chosen for its predictive potential, as discussed in the previous section, and because it is widely recognized. Figures 9 - 11 present the results of these analyses. The adopted values of the empirical parameter α ranged between 1.150 and 1.459, as recommended by the original authors for each textural class. It is important to note that the same soil may fall in different textural classes depending on the GSD method, as shown in Figures 7 and 8. Furthermore, the selection of these two soils for this analysis was strategic: the soil from Brasília represents a typical deeply weathered material, while the soil from Aparecida de Goiânia represents a commonly found moderately weathered soil.

The SWCC predictions of the bimodal soil from Brasília reveal a very high sensitivity of the pedotransfer model to the wide range of GSDs. None of the predicted SWCCs matched the experimental data across the entire curve. GDSs prepared under conditions that tend to preserve aggregates produced better predictions for the macropore regions of the SWCC. Conversely, GDSs prepared under conditions that tend to destroy the aggregates yielded better predictions for the micropore regions of the SWCC, particularly in the case LG-D. The GSD obtained through conventional particle-size analysis of samples prepared without drying and using defloccullant (CG-D-Nwc) provided the best overall results,

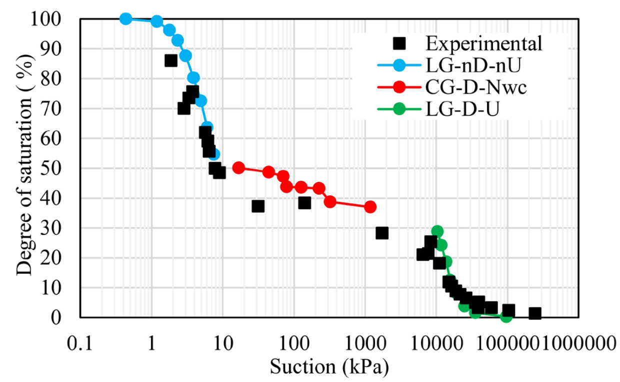

Figure 10. Segmental analysis of the SWCC of the soil from Brasília (DF).

offering a good balance between the macropore and mesopore regions. However, the GSD data from this latter condition did not include fractions that are sufficiently small to allow quantification of the micropore region. Quantitative model adherence values are not presented now, since no GSD allowed the adequate prediction of the entire SWCC for the soil from Brasília.

The main findings obtained from the results shown in Figure 9 indicate that tropical soils with particle aggregation require a combination of GSDs determined using different approaches. Specifically, combining GSDs obtained from experimental techniques that both preserve and destroy aggregates appears to be necessary. Figure 10 illustrates the combination of three GSDs, applied to the soil from Brasília. The adherence indicators for this analysis were $R^2 = 0.935$ and $RMSE = 0.067$, being the best predictions found in this research. The values of the parameter α used were the same as those proposed by Arya & Paris (1981), according to each GSD used: macropore zone (α = 1.285 – sandy material), mesopore plateau (α = 1.15 – silty loam material), and micropore zone (α = 1.16 – clayey material). It is important to note that to confirm the assumptions about the division of the macro-, meso-, and micropore regions in tropical soils, more experimental data with different methodologies of GSD determination are needed.

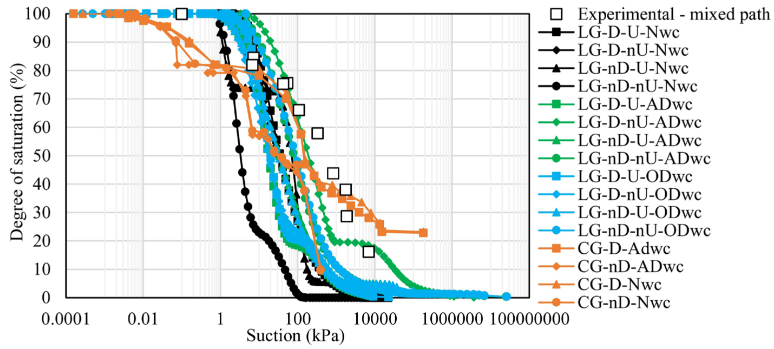

Figure 11. Prediction of the SWCC of the soil from Aparecida de Goiânia (GO) using the Arya & Paris (1981) model.

The results shown in Figure 11 for the Aparecida de Goiânia soil have a narrower range, as the GDSs of this soil are less sensitive to the analysis method compared to the soil from Brasília. The best SWCC prediction was obtained using the GSD determined using deflocculant, both with (R^2 = 0.874 and *RMSE* = 0.041) and without prior drying (R^2 = 0.816 and *RMSE* = 0.050). For these particular GSDs, the empirical parameter α was equal to 1.459, representing a loamy sand material. These results indicate that the SWCC of moderately weathered soils can be predicted using a single GSD, provided that it represents the particles in a dispersed condition. However, more experimental data of unimodal characteristic curves and GSDs determined by different methodologies are needed to validate the conclusions of this analysis.

5. Conclusions

This article aimed to evaluate the predictive performance of four widely used physico-empirical pedotransfer models in estimating the soil-water characteristic curve (SWCC), specifically when applied to tropical soils. The models analyzed were Arya & Paris (1981), Arya & Dierolf (1989), Aubertin et al. (2003), and Wang et al. (2017). These models use soil physical properties as input variables, including grain-size distribution (GSD), void ratio, specific grain density, and liquid limit. A database consisting of 95 datasets was compiled. Tropical soils with varying degrees of weathering are included in the database, among them bimodal soils with high contents of fine-particle aggregations. Because the GDS of some tropical soil is highly sensitive to the method of sample preparation, data obtained using approaches that either preserve or destroy particle aggregations were evaluated as input to the models.

The analyzed models exhibited unsatisfactory performance, with mean R^2 values being negative and mean *RMSE* values around 0.1, indicating poor agreement between the predicted curves and the experimental data. None of the pedotransfer models proved to be consistently superior. These results suggest that, in their original forms, the models are not suitable for application to tropical soils.

Given the unsatisfactory results, a critical analysis of the representativeness of GSDs used as input parameters was conducted. This analysis was necessary because the GSD can significantly influence prediction outcomes. The findings indicated that the GSD of soil in a disaggregated state yields better predictions for poor to moderately weathered soils. However, the high content of aggregates found in highly weathered soils requires a combination of GSDs, in which the curves obtained with aggregations preserved become important for estimating the SWCC along its macropore regions.

Due to the heterogeneity of the database, it was not possible to establish definitive guidelines for developing predictive models applicable to tropical soils. Nevertheless, the results of this study highlight the need to incorporate several geotechnical aspects discussed herein into models specifically tailored for tropical soils. This study also demonstrated the importance of developing a standardized database, the need to consistently provide detailed information about the adopted GSD testing protocols, and the necessity of determining the GSD in both aggregated and disaggregated states.

Pedotransfer functions do not replace direct determinations of SWCCs under most practical conditions. These approximations should always be calibrated to specific soils to increase their reliability. Nevertheless, pedotransfer models can be considered necessary and appropriate in situations involving large-scale analyses and preliminary studies. In addition, the exercise conducted during the development of physico-empirical models provides important insights into the fundamentals of soil behavior. In this regard, this study can be considered a step forward, as it demonstrated the importance of certain key soil properties to the storage mechanisms of tropical soils.

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Declaration of interest

The authors have no conflicts of interest to declare.

Authors' contributions

Fernando Carolino da Silva: conceptualization, data curation, methodology, visualization, validation, writing – original draft. José Camapum de Carvalho: conceptualization, methodology, supervision, funding acquisition, project administration, writing – review & editing. Gilson de F. N. Gitirana Junior: conceptualization, methodology, supervision, writing – review & editing. Isabela Cristina Mesquita Machado: validation, writing – review & editing. Renato Marques Cabral: validation, writing – review & editing.

Data availability

The data used in this study are available in Silva (2022).

Declaration of use of generative artificial intelligence

This work was prepared without the assistance of any generative artificial intelligence (GenAI) tools or services. All aspects of the manuscript were developed solely by the authors, who take full responsibility for the content of this publication.

List of symbols and abbreviations

n	van Genuchten fitting parameter
C_U	Uniformity coefficient
D_{10}	Diameter of the particle for which 10% of the total sample is smaller
D_{60}	Diameter of the particle for which 60% of the total sample is smaller
R^2	Coefficient of determination
GSD	Grain-size distribution
RMSE	Root mean square error
SWCC	Soil-water characteristic curve
USDA	United States Department of Agriculture
α	Empirical parameter of the Arya & Paris (1981) model
α^*	Empirical parameter of the Arya & Dierolf (1989) model

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