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Research Article

Large-Scale Assessment of Soil Physical Quality of Rural Settlements in the Southeast of Goiás, Brazil

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Land use and soil physical quality are related. In this work, the S index was used to evaluate the physical quality of the soils of three rural settlement units located in the Brazilian Cerrado, with areas ranging from 700 to more than 4000 hectares, based on a novel method. To map the *S* index, a set of pedotransfer functions for water retention curves was adapted according to a broad range of clay content for Cambisols, in three depth layers. Some rural units presented associations with classes of land use. In general, deeper layers presented higher values of *S*. In areas with less than 370 g/kg of clay, land uses that provide low soil cover should be avoided to prevent physical degradation.

1. Introduction

In Goiás, in the Center-West region of Brazil, there are more than three hundred units of rural settlements across the state, representing approximately 7204 km^2 [1]. Some of these units, however, have very different realities regarding the technological level and technical profile of production adopted by the occupants of the land, and in terms of the natural resources available, in particular the soil. This diversity can make it difficult to identify similar production units and, consequently, to define strategies for creating public policies for the analysis of the ownership of the land, to make the National Agrarian Reform Program (PNRA) viable.

Evaluating the use of natural resources and the dynamics of soil coverage is of great importance for the definition of public policy [2]. That is because land occupation rarely requires the conversion of native areas into anthropized areas, which changes the status of natural resources, vegetation, and water availability [3]. In addition, rural settlement areas often inherit the environmental status of monoculture. Nonetheless, there are reports [4, 5] of positive impacts on the physical quality of soils over time due to the land management adopted. However, this type of study may not be feasible to be carried out *in situ* on large scale, given the limitations of time and resources [6], but it can be performed efficiently through remote sensing [7, 8].

In the Brazilian Cerrado (Savanna), smooth topography favors soil management, but it can also lead to structural degradation [9, 10]. Thus, it is of remarkable importance to monitor the physical and structural quality of those soils to avoid irreversible degradation. Dexter [11–13] has proposed to assess soil physical and structural quality through the S index, an attribute that can be determined from the soil water retention curve (SWRC) as the slope at its inflection point, with which higher values are associated with better pore distribution. *S* index can be used to quantify the modifications to soil physical quality by management practices, with the advantage of being comparable in different soils [14]. Tormena et al. [15] verified an inverse relationship between the *S* index and soil compaction in a Brazilian Oxisol, where it was also able to discriminate soil management systems. For soils of southwest China, Xu et al. [16] suggest that the *S*

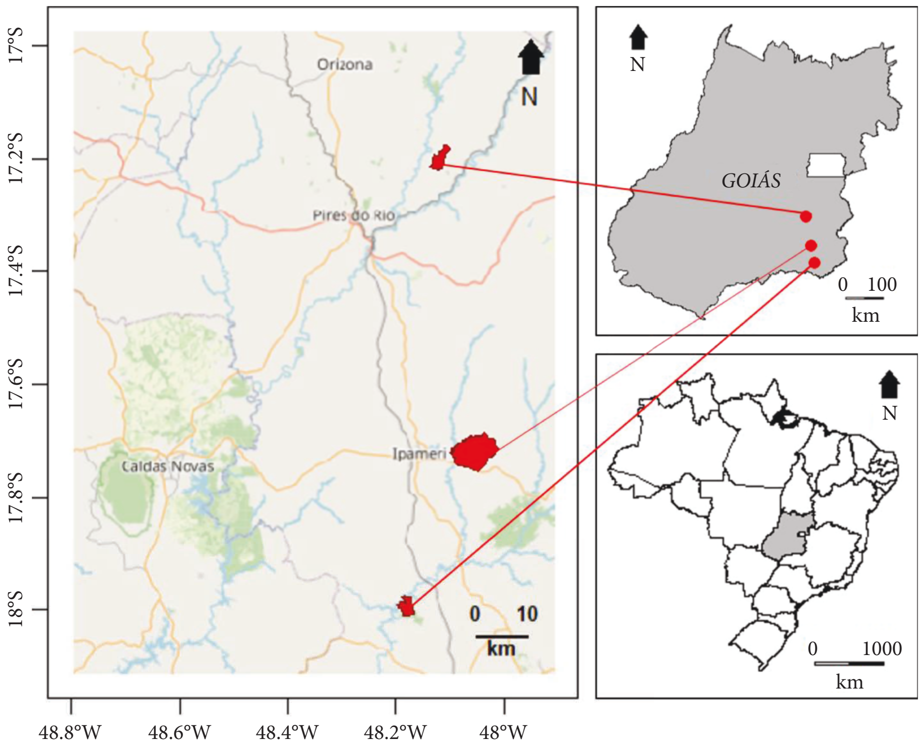

FIGURE 1: Location of the study areas in the southeast of Goiás, Brazil. Basemap: OpenStreetMap®.

index has the potential in indicating land management in the catchment scale. *S* index was used to assess the structural quality of Latosols cultivated with maize [17] and of soils in the Cerrado cultivated with coffee [18].

Monitoring the physical status of the soil is, however, not likely to be viable on large scale using traditional methods originally dependent on laboratory analysis, which are usually time demanding and costly. For the *S* index, soil samples should be taken to obtain the SWRC in the laboratory. Other attributes such as penetration resistance, bulk density, hydraulic conductivity, porosity, and aggregation can be used [19, 20], but with the same practical restrictions. In an innovative work, Souza et al. [7] presented a remote sensing approach to map soil load-bearing capacity using satellite data combined with pedotransfer functions, thus unraveling zones of risk of compaction. Similarly, the aim of the present work is to present a novel approach to mapping the soil's physical quality in rural settlements in the southeast of Goiás, for which methodological details are given in Section 2.2.

2. Material and Methods

2.1. Study Areas. The data used in this study are from the Rural Settlement Projects in the southeast of Goiás state, as presented in Figure 1 and described in Table 1.

The climate of the region is of type Aw (semihumid tropical with summer rains), according to Köppen's classification. In the last ten years, the mean annual air temperature ranged from 22.7°C to 24°C, the mean relative air humidity ranged from 60% to 70.7%, and the mean annual rainfall varied from 964 to 1460 mm [21], with rains concentrated from October to March. The native vegetation consists of the Brazilian Cerrado (Savanna) domain with physiognomies ranging from dense trees (*Cerradão*) to grassy woody plants.

According to IBGE [22], approximately 89% of "Olga Benário" and 85% of "Madre Cristina" was classified as natural pasture, and 67% of "Maria da Conceição" was classified as a mosaic of forest with agricultural areas. Dystrophic Haplic Cambisol (86–97%) and Red Acric Latosol (2–14%) are the dominant soil classes of the three rural settlements [23]. The landscape varies from flat to smoothly undulating topography, with a mean slope of 9.4%, which favors agricultural practices and conventional agriculture. The family production of domestic sustenance and its surpluses persists in the three settlement units. Production consists of the cultivation of crops such as corn, cassava, rice, beans, soybeans, coffee, sugar cane, and vegetables [24].

2.2. Soil Physical Quality Assessment. The soil physical and structural quality of the soils under study were evaluated through the *S* index, which is usually based on van Genuchten [25] equation (1) for the soil water retention curve, a parametric function for the relationship between soil water content (θ, m^3/m^3) and matric potential (h, cm).

$$\theta = \theta_R + (\theta_S - \theta_R)\left[1 + (\alpha h)^n\right]^{-m}, \quad (1)$$

where θ_R is the residual soil water content, θ_S is the saturated soil water content, α is a scale parameter and n is a shape parameter; the parameter m is sometimes defined according

Table 1: Description of the study areas.

Study area	Municipality	Geographic coordinates	Area (ha)
Maria da Conceição	Orizona—GO	16.79544°S, 51.36882°W	790.88
Olga Benário	Ipameri—GO	17.71977°S, 48.05414°W	4174.86
Madre Cristina	Goiandira—GO	17.99450°S, 48.18018°W	732.64

Table 2: Parameter estimates for water retention curves of Cambisols adapted from Oliveira et al. [27].

Clay content (g/kg)	θ_R	θ_S	α	m	N
$L \leq 270$	0.077	0.406	0.946	0.063	2.680
$270 < L \leq 370$	0.000	0.475	0.227	0.551	0.274
$370 < L \leq 470$	0.066	0.476	2.172	0.066	3.789
$470 < L \leq 580$	0.037	0.442	1.240	0.050	3.337
$L > 580$	0.020	0.514	1.812	0.047	3.165

to the Mualem [26] restriction: $m = 1 - (1/n)$. The S index (equation (2), dimensionless) corresponds to the slope of equation (1) at its inflection point. Its absolute value was computed.

$$S = -n\left(\theta_S - \theta_R\right)\left[1 + \frac{1}{m}\right]^{-1-m}. \quad (2)$$

The estimates of the parameters θ_R, θ_S, α, m, and n used to calculate the S index are given in Table 2. They were retrieved from a set of pedotransfer functions fitted by Oliveira et al. [27] for Haplic Cambisols, as that was the dominant class found in the study areas. Estimates were clustered according to a broad range of clay content, as suggested by Souza et al. [7] and Severiano et al. [10]. Besides, according to Dexter [11], the S index is influenced by soil porosity, thus keeping a close relationship with texture. Data on clay content were obtained from maps retrieved from the GeoInfo platform by Embrapa Solos [28], for the layers 0–5, 5–15, and 15–30 cm depth, with a spatial resolution of 90 m.

Dexter [11] suggested that 0.035 can be taken as the limit between good and poor structural quality and that a value below 0.020 indicates very poor physical quality, based on the evaluation of soils of Poland and England. In the present work, those respective limits were taken as 0.045 and 0.025 to classify the soils of the study areas, following the findings of Andrade and Stone [29] for some soils of the Brazilian Cerrado.

Data management and analysis were performed in R version 4.1.1 [30]. The S index is implemented in the package soil physics [31], which was thus used for predictions on the sampling grids.

3. Results and Discussion

Figure 2 contains the values of the S index for the three study areas, in different depth layers. On average, the estimates of S for the three layers of "Olga Benário" and "Maria da Conceição" were around 0.07, considered high, but very similar to the values found by Nascimento et al. [32] for a Cambisol. On the other hand, S for "Madre Cristina" varied from 0.029 (0–15 cm) to 0.036 (15–30 cm), in average.

In the first layer, 0–5 cm, approximately 80% of "Olga Benário" presented S above 0.045, while in layers 5–15 cm and 15–30 cm, 82% and 91%, respectively, of the area presented at least good physical quality. There were no estimates indicating very poor physical quality ($S < 0.025$), which would be restrictive to the development of roots of many cultivated species. No association between the spatial distribution of S and land use was noticed—variations in S were a function of clay content because it is known to affect S due to changes in soil porosity, structure formation, and water retention capacity [33, 34].

The first two layers of "Madre Cristina" presented poor physical quality ($S < 0.045$) in almost 95% of the area. In layers 15–30 cm, only 19% of the area presented $S > 0.045$. No association between the spatial distribution of S and land use was noticed.

"Maria da Conceição" presented results similar to "Olga Benário," with 84% (0–5 cm), 89% (5–15 cm), and 96% (15–30 cm) of good physical quality. The largest portion of the area classified as a mosaic of forest and agriculture (data not shown) presented higher values of S.

On average, "Madre Cristina" had lower values of clay content, ranging from 317 (0–5 cm) to 348 g/kg (15–30 cm), than the other two areas, which have values around 400 g/kg (0–5 cm) and 420 g/kg (15–30 cm). Nonetheless, in general, deeper layers presented higher physical quality, which is possibly a consequence of an increase in pore diameter in more superficial layers due to mechanized soil preparation [18].

In "Olga Benário," land uses that provide low soil cover such as pasture should be avoided, particularly in fields with less than 370 g/kg of clay. This is inferred from what was found in regions with similar texture in "Maria da Conceição," probably due to the presence of native vegetation. Studying Haplic Cambisols, Oliveira et al. [27] found that preserved forest areas presented the best water retention conditions, which is significantly correlated with S [35], thus endorsing the conjecture in the present work. Moreover, as illustrated in Dexter [11], the S index is mostly determined by soil organic carbon, being positively correlated [36], since organic carbon can increase water retention and improve pore distribution [37]. In addition, the S index can be particularly increased in the layer 0–5 cm under carbon deposition [14]. And, according to Shekofteh and Masoudi [33], when the clay content is low, organic matter has a larger

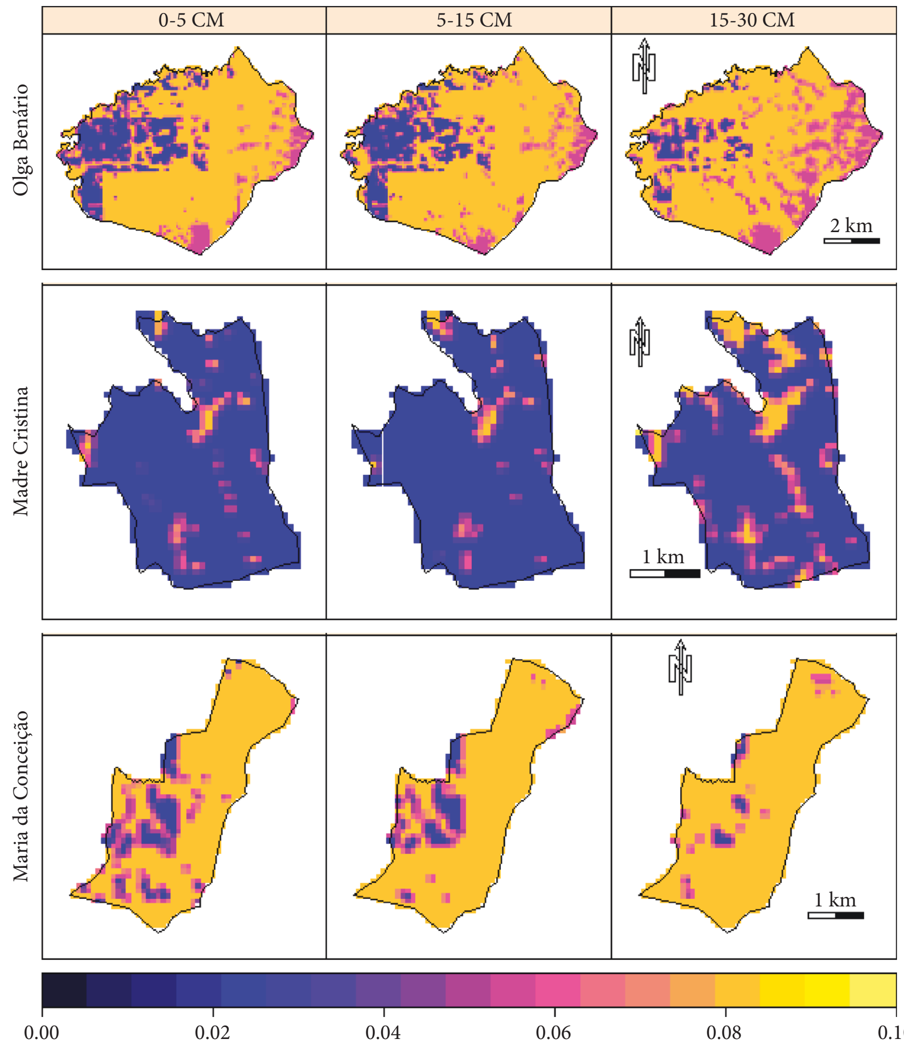

Figure 2: Estimates of *S* index for three rural settlement areas in the southeast of Goiás, Brazil, in three depth layers: 0–5, 5–15, and 15–30 cm.

effect on the *S* index. That is probably the reason "Madre Cristina" presented low values of *S*. In this case, one alternative to improve soil structural conditions is to introduce techniques of crop-livestock-forest integration.

4. Conclusion

In this study, the S index was used to assess soil physical quality, based on the water retention curves of Cambisols. A set of pedotransfer functions is adapted for prediction according to a broad range of clay content, thus allowing the mapping of soil's physical quality even on large scales.

Three rural settlement units in the Brazilian Cerrado were mapped in terms of soil physical quality for layers 0–5 cm, 5–15 cm, and 15–30 cm. In general, the latter presented larger estimates of *S*. One of the units was identified to have a restricted physical condition of soils for agriculture.

Future works should move in the direction of dynamic indicators of soil physical quality of rural settlements, with different approaches, such as load bearing capacity and least limiting water range.

Data Availability

Data are available on request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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