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GILGAI MICRORELIEF MORPHOLOGY IN THE CAICÓ – RN REGION

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ABSTRACT
The Gilgai microrelief is characterized as a succession of alternating micromounds and depressions, in soils rich in expansive clays (2:1). Its genesis is related to successive cycles of wetting and drying, especially pronounced under conditions of imperfectly or poorly drained soils. There are still many gaps in the literature on the genesis, evolution and dynamics of the processes involved in areas with Gilgais in Brazil, so studies aimed at understanding their patterns of occurrence are necessary. Thus, the aim of this study is a morphological characterization of Gilgais, in the Potiguar semi-arid region, to verify the hypothesis of homogeneity of its patterns of regional occurrence. The analyzed data refer to two sampling sites, where a total of 120 micro-reliefs were measured, in relation to their height, width and distance between micromounds. Descriptive statistical analysis and ANOVA analysis of variance were applied to the data, seeking to understand the patterns of occurrence of microreliefs. The Gilgai microreliefs observed in the two sampling sites present morphological patterns specific to each site, and differ in some aspects. In both places studied, the micro-reliefs were classified as isometric shapes with no defined orientation. However, in terms of height, width and distance between micromounds, the two sampling sites present statistically significant differences, demonstrated through the analysis of variance of the ANOVA statistical test. This indicates that despite having similar shapes, the size proportions and spacing patterns of the micro-reliefs found in each location are different, ruling out the hypothesis of homogeneous patterns of regional occurrence.
Keywords: morphology, Caicó; Gilgai

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MORFOLOGIA DE MICRORRELEVOS GILGAI NA REGIÃO DE CAICÓ – RN

RESUMO

O microrrelevo Gilgai é caracterizado como uma sucessão de micromontes e depressões alternados em solos ricos em argilas expansivas (2:1). Sua gênese está relacionada a sucessivos ciclos de umedecimento e secagem, especialmente pronunciados sob condições de solos imperfeitamente ou mal drenados. Ainda existem muitas lacunas na literatura sobre a gênese, evolução e dinâmica dos processos envolvidos em áreas com Gilgais no Brasil, dessa forma estudos visando a compreensão de seus padrões de ocorrência são necessários. Desse modo, a proposta deste estudo é uma caracterização morfológica de Gilgais, na região semiárida potiguar, para verificação da hipótese de homogeneidade de seus padrões de ocorrência regional. Os dados analisados são referentes a dois sítios amostrais, onde foram medidos um total de 120 microrrelevos, em relação à sua altura, largura e distância entre topos. Análises de estatística descritiva e a análise de variância ANOVA foram aplicadas aos dados, buscando entender os padrões de ocorrência dos microrrelevos. Os microrrelevos Gilgai observados nos dois sítios amostrais apresentam padrões morfológicos próprios de cada local, e se diferem em alguns aspectos. Em ambos os locais estudados os microrrelevos foram classificados como formas isométricas sem orientação definida. Porém, quanto às suas medidas de altura, largura e distância entre topos, os dois sítios amostrais apresentam diferenças estatisticamente significativas demonstradas através da análise de variância do teste estatístico ANOVA. Isso indica que apesar de apresentarem formas semelhantes, as proporções de tamanho e padrões de espaçamento dos microrrelevos encontrados em cada local são diferentes, descartando a hipótese de padrões

Palavras-chave: morfologia, Caicó; Gilgai

INTRODUCTION

In Brazilian literature, the Gilgai microrelief is defined by EMBRAPA (2018) and IBGE (2015) as convex ridges in flat sites or microtopographies with a succession of small depressions and elevations that are commonly associated with clayey soils that expand with increasing moisture content, and subsequently contract when dried.

The term Gilgai is designated by Paton (1974) as mounds and depressions that repeat and alternate in clayey soils that expand their volume when wet and crack when dry during drought. The words crabhole, melonhole and Gilgai are attributed to the Kamilaroi, Wiradhuri and related aboriginal languages, in which they mean a small well of water at the bottom of the land (PATON, 1974). Crabhole and melonhole are little used concepts, since the Gilgai terminology is widely used to represent all the aforementioned features (KHITROV, 2016a).

Gilgai formation is related to soils with a high content of expansive clays (2:1), which when exposed to cycles of wetting and drying tend to exhibit expansion and contraction behavior. Dehydration of 2:1 clays results in the formation of surface and subsurface cracks that can receive material from the upper horizons by biological, wind and/or hydric action. In such a way, the filling of the cracks occurs, receiving solid particles where air and/or water were previously found. The re-wetting of the soil generates the incorporation of these solid particles into the cracks, which to rebalance the expansion laterally, forces the blocks of subsurface materials upwards, forming the raised features of the microrelief on the surface (LIMA, 2014; PATON, 1974; WONDZELL et al. al., 1990). The term Gilgai, by definition, is not used for microtopographies created by living organisms, originated by erosion or by freeze-thaw cycles (FLORINSKY and ARLASHINA, 1998; KHITROV, 2016b; KHITROV, 2016c).

The influence of Gilgai on the soil surface occurs in water percolation, via contraction and expansion of cracks, in mineralogical, physical and chemical properties, implying changes in the distribution of water in the soil and indirectly in nutrients, oxygen, pH and iron. (LIMA, 2014; KOVDA et al., 1992).

Gilgai microrelief is commonly associated with Vertisols, which have good fertility, but physical limitations make their use difficult, either because of its clayey texture with the common presence of expandable clay minerals, its hardness in the absence of moisture, or its very limited permeability and infiltration (AYDINALP, 2010; FAO, 2014; LIMA, 2014). Khitrov (2016a) discusses that Gilgais can be found in different types of soils, being frequent in the Vertic Planosols (Albic, Episiltic, Endoclayic) on the river terraces of the Gilgel Giba basin in the southwestern part of the Ethiopian Plateau, at 1100 m above sea level, and in the Haplic Thaptovertic Calcisol (Abruptic, Ruptic, Endoskeletic, Endoclayic) in the south of the province of Malaga, Spain. However, the Gilgai microtopography is buried at a depth of 40 cm with an undulating limit to the upper horizon, different from the conditions described in Brazilian territory (LIMA, 2014). The development of Gilgai tends to be moderate when derived from basic rocks and weak when derived from sediments (MERMUT et al., 1996).

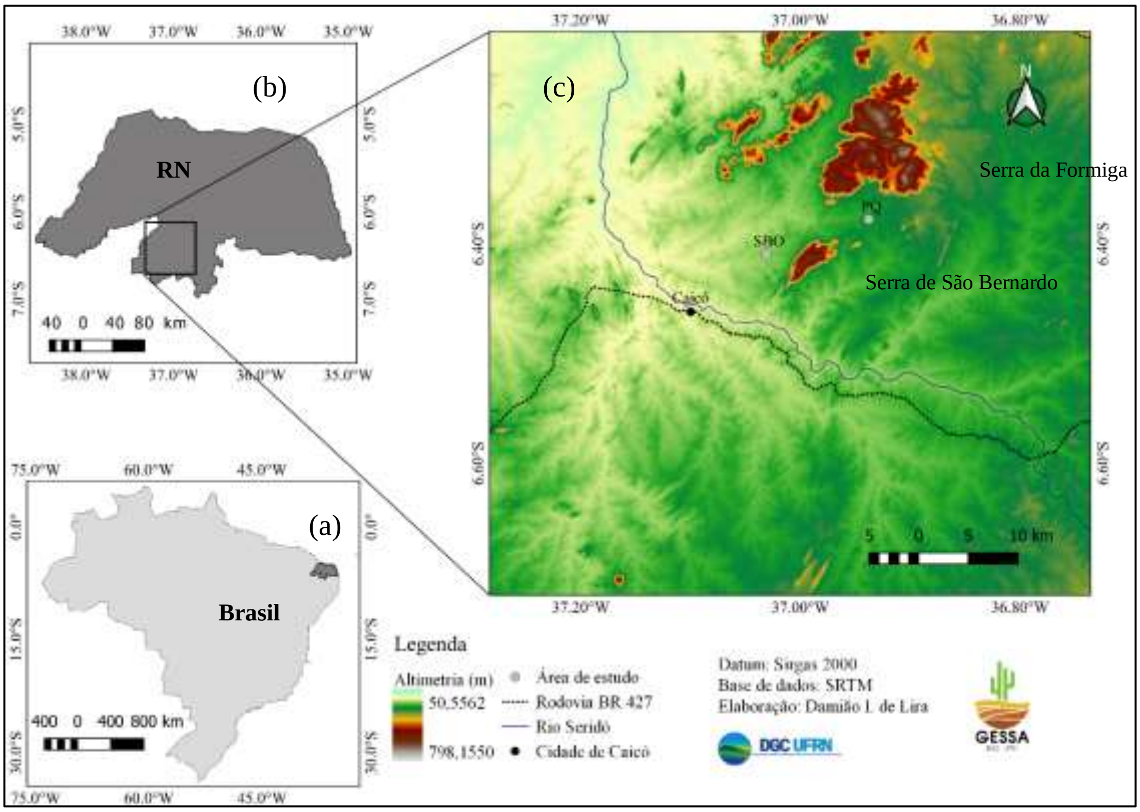
There are still many gaps about the understanding of Gilgais in Brazilian literature, although their occurrence is documented. Based on the above, the objective of the present work is to understand the diversity and patterns of occurrence of Gilgai microreliefs in the region of Caicó (RN), through the quantification of aspects related to their morphology.

MATERIAL E MÉTODOS

The sampling sites are located in the municipality of Caicó - RN (Figure 1). The first sampling point is near the rural property Pedra do Queijo (PQ), 18 km from the city of Caicó and northeast of the Serra de São Bernardo. While the second sampling point is located west of the Serra de São Bernardo (SBO) near the Alegre rural property, 7.5 km from Caicó (Figure 1). The identification of sites with potential for Gilgai microrelief formation, and the possibility of data collection, was carried out with the aid of pattern recognition from satellite images and correlations through field activities.

The local relief is formed by low lands of the Sertaneja Setentrional Depression, ranging from flat to smooth undulating (COSTA, 2006). The monotony of the relief is broken by the occurrence of few residual crystalline massifs to the north and northeast, which in the study site are close to the sampling points, with PQ between Serra da Formiga and Serra de São Bernardo, and SBO to the west of the latter (Figure 1). The relief of the municipality of Caicó is dominated by planing surfaces, with the regional relief aligned in the SW-NE direction (SANTOS and VITAL, 2020).

Figure 1. Mapa de localização e hipsométrico da região dos sítios amostrais estudados.



The climate of Rio Grande do Norte has only one large-scale system responsible for precipitation, the ITCZ (Intertropical Convergence Zone). The ITCZ seasonally migrates from the north (14° N, August-September) to the south (2°, March-April). In years with above-average rainfall, the ITCZ can reach up to 5° south (MELO et al., 2009). The displacement of the ITCZ is the main factor for the alternation of humidity in the environment under analysis. The climate of the study area in the Koppen classification is BSwh, hot semi-arid, with low average annual rainfall, with an average temperature of 27.4°C, which remains high throughout the year (ARAÚJO et al., 2003; IDEC, 1991). The average annual precipitation is 659.94 mm, and the insolation and evapotranspiration are high, disfavoring the accumulation of water in the environment (LUCENA et al., 2013), and providing rapid cycles of wetting and drying in shallow portions of the landscape.

The main lithology of the PQ is formed, mainly, by granites, with quartz fragments in gravel size or larger, being easily found in the analyzed soils. The regional geology of the sector is part of the Jucurutu Formation, from do Ediacarano period (635-541 ma), consisting of paragneisses, marbles, calcsilicates, micaschists, metavolcanics and iron formations (NASCIMENTO and MEDEIROS, 2008). The regional lithology of the SBO sector is located in the Caicó do Rhyaciano Complex (2300-2050 ma), which comprises migmatized banded orthogneisses that may present amphibolite intercalations, encompassing calc-alkaline granitic and diorite rocks (SOUZA et al., 1993, 2007; HOLLANDA et al., 2011; SILVA, 2018).

The predominant vegetation is anthropized Open Arboreal Arbustive Caatinga, with Closed Arboreal Arboreous Caatinga being found in areas with more restricted access, such as the Serra de São Bernardo and Serra da Formiga (ANA, 2005; SANTOS, 2016). The local vegetation is hyperxerophilous Caatinga with native pasture and predominance of pereiro (Aspidosperma pyrifolium), marmeleiro (Croton sonderianus), cactus, velame (Croton heliotropiifolius) and umburana (Commiphora leptophloeos).

The predominant soils are the Luvissolos Crômicos Órticos in smooth wavy relief associated with Neossolos Regolíticos with medium texture, stony phase or not, smooth wavy and flat relief. Planossolos and Vertissolos are also found less frequently, associated with lowlands or areas of seasonal water accumulation (JACOMINE et al, 1971), as in the case of the sampled points.

Agricultural preparation of soils with the presence of Gilgai can mask the features of the microrelief through human changes such as plowing and harrowing (AHMAD, 1996). Extensive livestock farming in the analyzed areas is the main source of degradation of the Gilgais, either through the consumption of vegetation used as pasture or the trampling caused by animals.

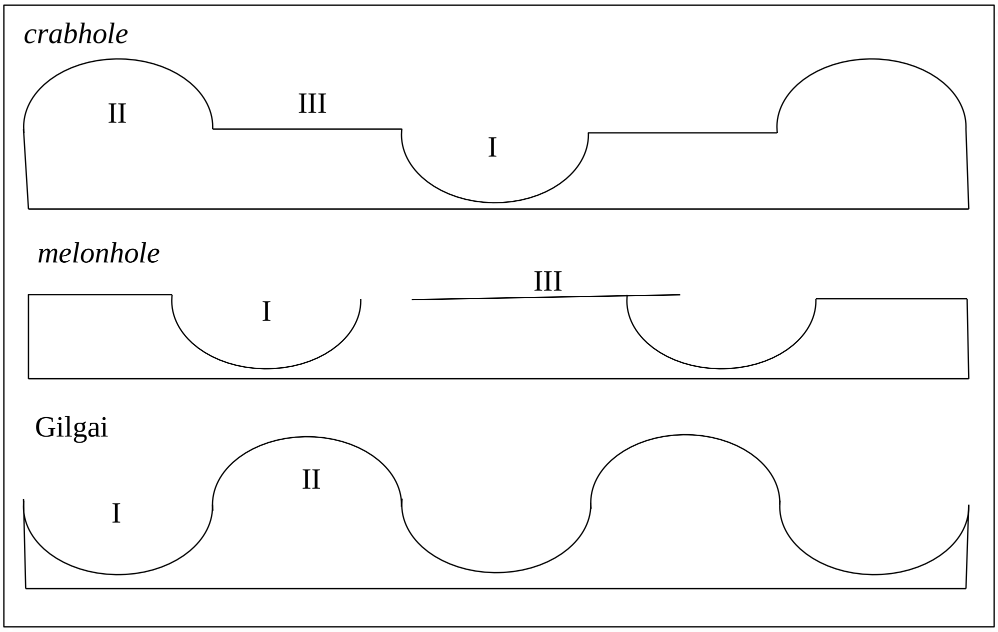
Gilgai microrelief configurations are diverse, alternating between three elements (Figure 2) according to Howard (1932): I) depression or lower position of the microrelief; II) micromound or superior position of the features; III) shelf. The standardization of the elements on the surface defines the typology of the microrelief. The literature describes 3 main types of Gilgai microrelief (Figure 2), according to Paton (1974), they are: the crabhole composed of depressions, micromounds and shelves; the melonhole corresponds to the configuration of depressions between shelves; and the typical Gilgai is the alternation between depressions and micromounds.

The formation of the shelf is attributed to the original soil surface that undergoes the development of depressions on both sides, similar to the appearance of crabholes according to Paton (1974). The greater amplitude in the development of the shelf causes the formation of micromounds and depressions.

The Gilgai microrelief includes 3 distinct groups based on their morphology according to Verger (1964) and Khitrov (2016b). Shapes can be termed isometric, elongated, or strongly elongated. The calculation considers the length (L) / width (W) ratio according to Table 1.

Verger's classification (1964) consists of the shape of the main elements of the Gilgai microrelief, the micromounds and depressions. Both features are grouped into eight distinct classes as the orientation and shape change (Table 1). The groups with Latin letters (a, b, c) are intended to represent the micromounds and the Greek letters (α, β, γ) to depressions, the features α^0 and γ^0 are represented by the following numbered form, α^1 and γ^1 respectively (Figure 4). Orientation is designated by values of 0, 1 and 2 as degree signs after the letter corresponding to the shape (KHITROV, 2016b). The junction between the aforementioned symbols defines the geometry of Gilgai and its orientation pattern within the classification.

Figure 2. Features present in the forms of the Gilgai microrelief: I - depression, II - micromount and III - shelf.



Source: Adapted from PATON (1974)

The morphometric data analyzed in this study refer to the two sampling sites, both separated into 4 sectors for data collection. In each sector, 15 features were sampled, totaling 60 measurements per site. The collection of data from the Gilgais consisted of measuring the height, being the distance between the base in the depression and the top of the micro-relief; the distance between the centers of the micromounds; and the diameter was calculated from the measurement of the width and length.

With the collected data, the descriptive statistics of the measurements of each sampling site were analyzed, and the microreliefs of the two sites were compared. The normality of the data was verified through the Shapiro-Wilk test, and the observation of histograms and density graphs. The statistical test of Analysis of Variance (ANOVA) was applied to verify statistically significant differences between the Gilgais of each location, aiming to test the hypothesis of homogeneity of the pattern of occurrence of the microrelief in the region.

RESULTS AND DISCUSSION

The analyzed microreliefs are all classified as isometric microforms, where the length (L) to width (W) L/W ratio < 2. The averages of the L/W ratio for the PQ and SBO sites are, respectively, 0.88 and 0.96. Gilgai without preferential orientation of the micromounds (a^0) was the only pattern found in both sampling sites. The reported Gilgai pattern can be seen in Figure 5.

Table 1. Calculation to define the type of Gilgai feature according to the relationship between length (L) and width (W) of micromounds and depressions

Element	**Types of microrelief shapes**	**Shape index by orientation difference and similarity of microrelief elements**		
		No preferred orientation	**Single preferred orientation**	**Several orientations**
Micromounds	**Isometric** L/W < 2	a^0	a^1	a^2
	Elongated 2 < L/W < 10	b^0	b^1	b^2
	Strongly elongated L/W > 10	-	c^1	c^2
Depressions	**Isometric** L/W < 2	α^0	α^1	α^2
	Elongated 2 < L/W < 10	β^0	β^1	β^2
	Strongly elongated L/W > 10	-	γ^1	γ^2

Source: Adapted from VERGER (1964)

The cracking process in Gilgais analyzed at the SBO sampling site is quite intense in relation to the PQ, reaching up to 3 meters in length and varying approximately from 4 to 7 cm in width (Figure 3). Part of the cracks were filled by material displaced from the upper horizons.

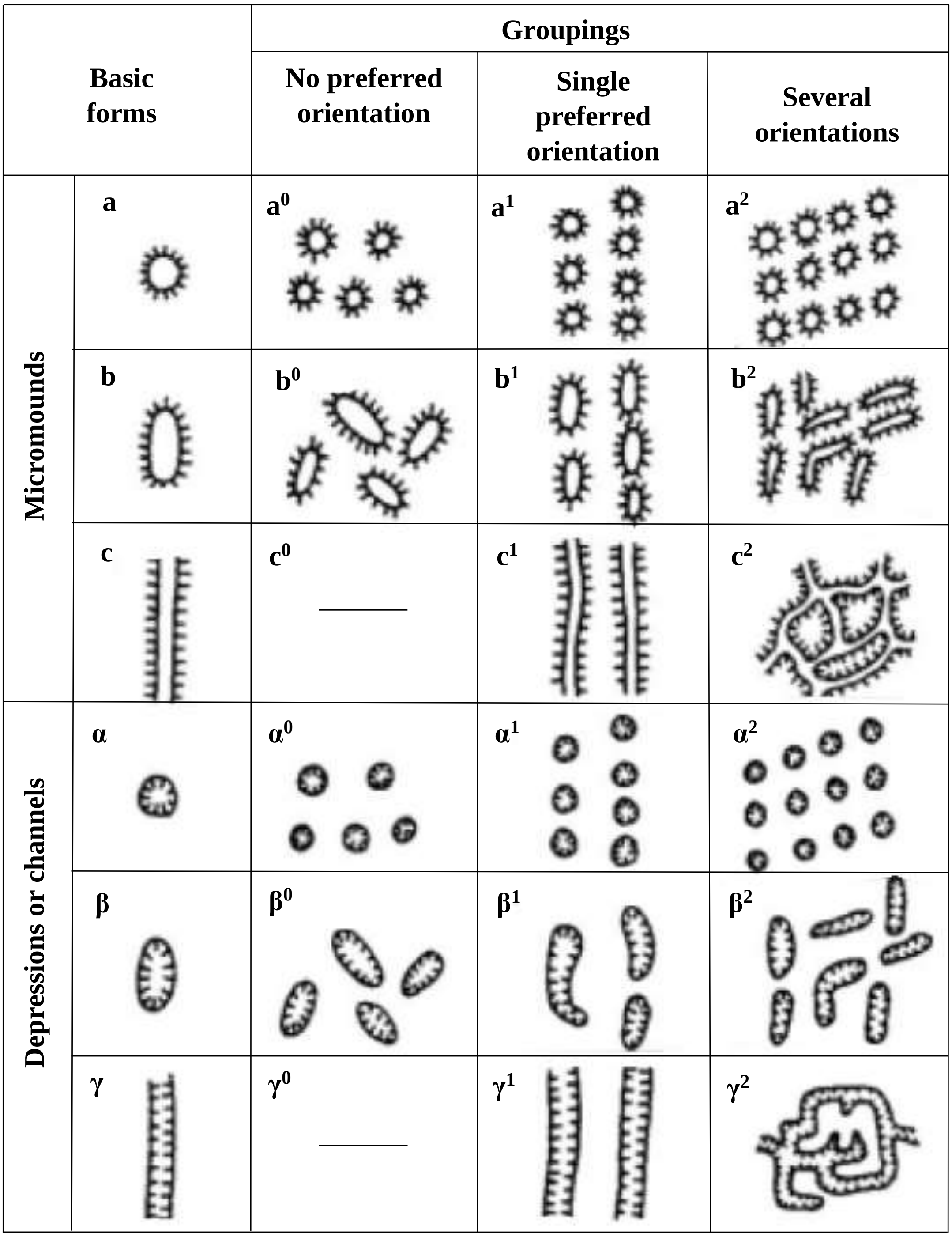
Figure 3. Presence of intense cracking and filling of the interior of the cracks by organic and mineral materials, in the Gilgais microreliefs of the SBO sampling site.

The height of the Gilgais varies between 15 and 45 cm (Table 2), however most of the micromounds measured were between 27 and 28 cm in the SBO and PQ sampling sites, respectively. The values are within the height range of areas analyzed by Florinsky and Arlashina (1998) and Maxwell (1998) with intervals of 20 to 100 cm and 7.6 to 45.7 cm, in Vertisols of the Stavropol region in Russia and the Texas in the United States, respectively.

The distances between the center of the micromounds varied between 75 and 200 cm. Observing the medians of the sample sites, it is verified that in SBO half of the values are below 114.5 cm, while in PQ below 140 cm. The distance pattern between Gilgais, as well as the slickensides are suggested by Wilding and Tessier (1988) as a result of the alternation of soil expansion and contraction cycles as a response to the variation of the climatic regime, however, there is still much to be studied about the Gilgai microreliefs in Brazil.

From the field observations, the texture of the soils and Gilgais at the PQ sampling site denotes very high silt contents, while in SBO it indicates higher clay contents. There is a work in progress by the same authors of this research, which seeks to analyze whether there is a correlation between morphological characteristics of Gilgai microreliefs and their respective contents of sand, silt and clay.

Figure 4. Classification of the morphology and orientation of the micromounds and depressions present in the Gilgais.



Source: Adapted from Verger (1964)

Figure 5. Gilgai microrelief from the PQ sampling site, showing representative morphology of the isometric micromound shape type without preferential orientation (a^0).

Table 2. Descriptive statistics for the variables width, height and distance between micromounds, of the sample sites PQ and SBO

	Width (cm)		Height (cm)		Distance between micromounds (cm)	
Sampling site	**PQ**	**SBO**	**PQ**	**SBO**	**PQ**	**SBO**
Minimum	50	50	15	18	104	75
1st Quartile	76,25	62	24	25	123	100
Median	85	71,2	28	27	140	114,5
3rd Quartile	95	83,5	33	29	152	137
Maximum	131,5	118	45	35	200	155
Mean	86,8	74,5	28,3	27,1	141,3	115,9
Standard deviation	15,7	16,4	5,8	3,7	21,0	21,4
Coefficient of variation (%)	18,0	20,9	20,6	13,5	14,8	18,4

The results of the Shapiro-Wilk test (Table 3), as well as the observation of density plots (Figure 6) and qq-plot plots (Figure 7), indicate normal distribution of the data. Based on this assumption, the parametric ANOVA test was applied to verify the statistically significant difference between the Gilgais measurements of the sample sites.

Figure 6. Density plots of measurements values about height (a), width (b), and distance between micromunds (c) of the studied Gilgai microreliefs.

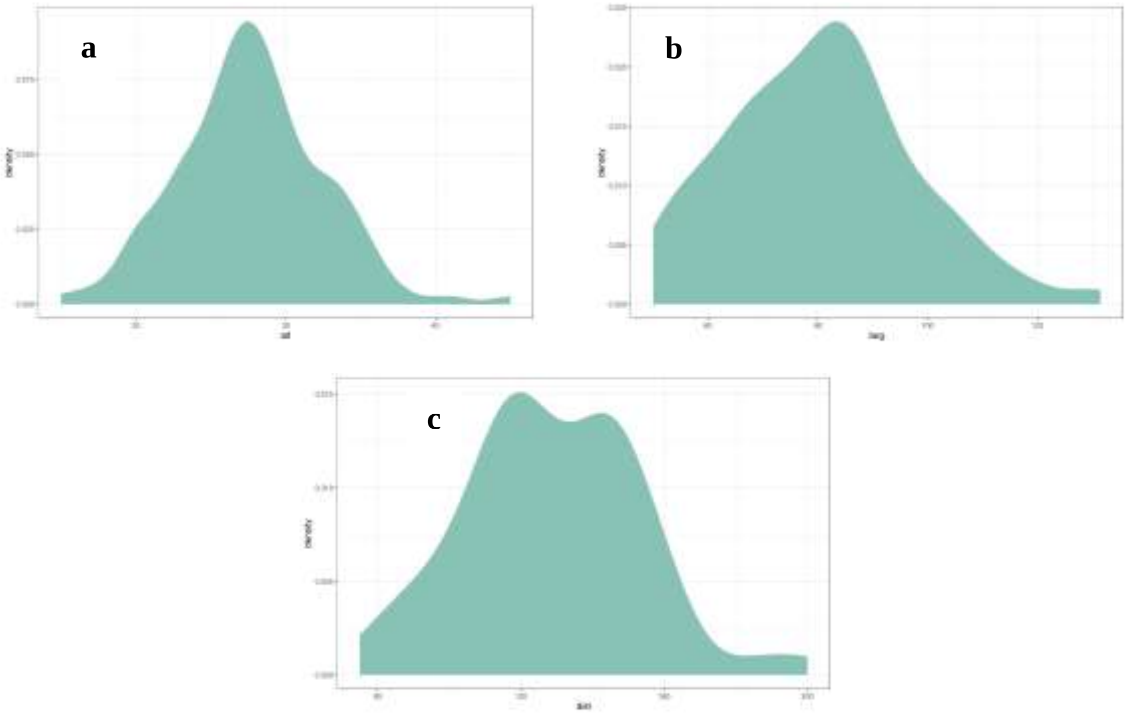
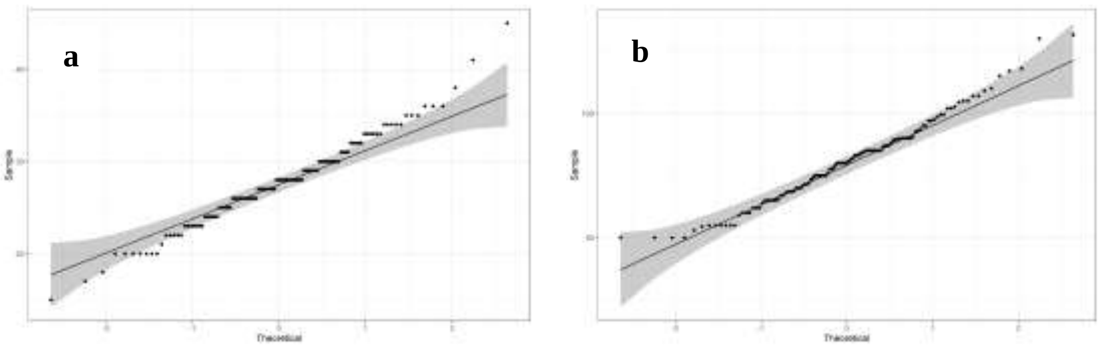


Figure 7. Qq-plot plots of measurements values about height (a), width (b), and distance between micromounds (c) of the studied Gilgai micro-reliefs.



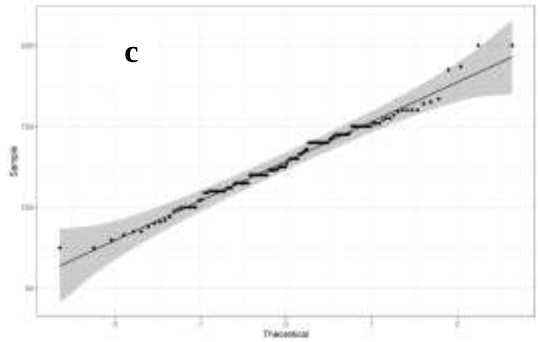
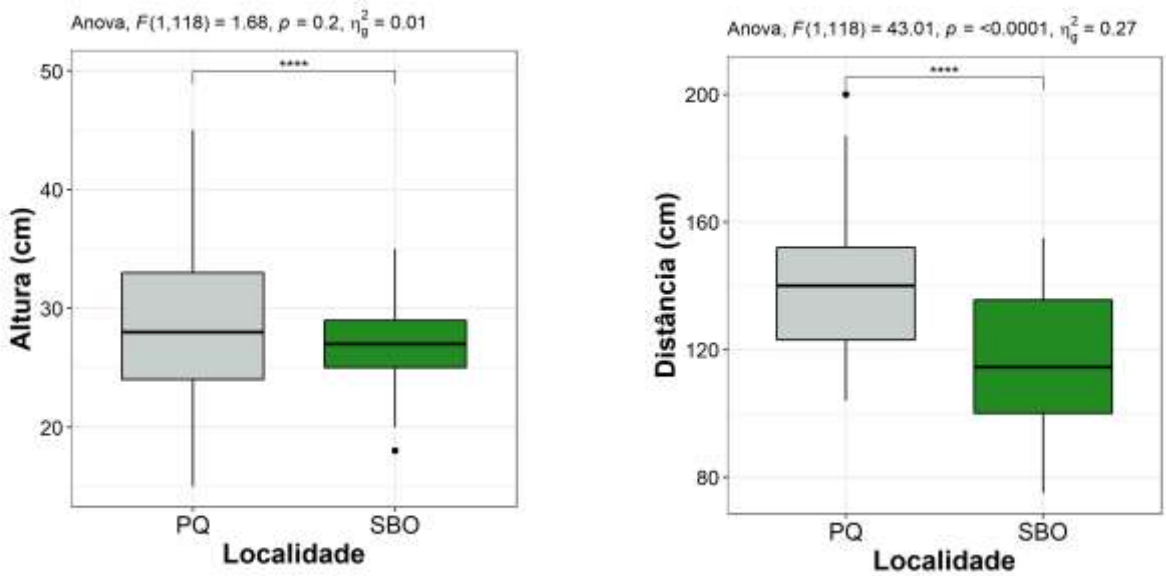


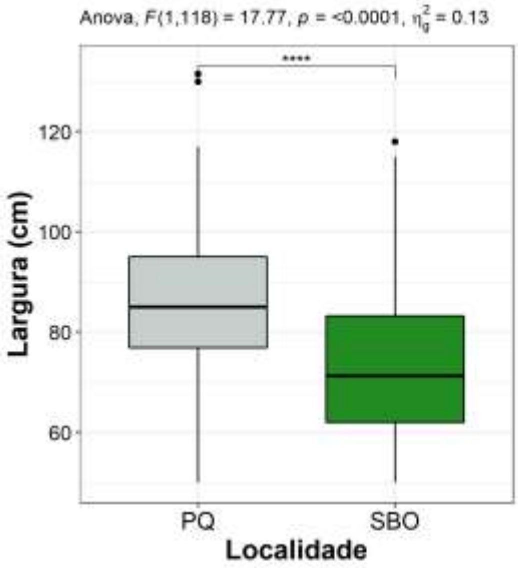
Table 3. ρ-value result of the Shapiro-Wilk normality test for the variables height, distance between micromounds and width at 5% significance (ρ > 0,05**).**

Variable	p-value
Height	0.179
Distance	0.159
Width	0.070

The ANOVA variance analysis points to a significant difference for all variables between the sampling sites (Figure 8). The SBO site has Gilgais with smaller height amplitude, smaller distance between micromounds and smaller width in relation to the PQ.

Figure 8. Boxplot plots of the variables height, width, and distance between micromounds of the analyzed Gilgais micro-reliefs, with their respective results of the ANOVA statistical tests.





Gilgais height values showed greater amplitude in the PQ site in relation to the SBO, explaining the significant difference between the sites. The SBO values are closer to the median, with a smaller standard deviation in relation to the PQ (Table 2). The median between the two sampling sites is practically the same, which demonstrates that there is a similar height pattern between the two sites for most of the individuals measured.

The distance variation between Gilgai micromounds in the two sampling sites is practically the same, according to standard deviation values (Table 2). However, the lower mean and median values in SBO indicate greater proximity between micromounds, and consequently higher density. Such observations suggest the understanding that there is a well-defined pattern of distance between micromounds for each sampling site, but these patterns differ in the two studied sites.

The width of the microreliefs of the PQ site is predominantly greater than the SBO, indicating the predominance of larger micromounds, characterizing two different sizes between the analyzed sites (Figure 9). The width of the micromounds is between 50 and 131.5 cm. The median observed for PQ (85 cm) is greater than the value for SBO (71.25 cm).

CONCLUSIONS

The Gilgai microreliefs observed in the two sampling sites present morphological patterns specific to each site, and differ in some aspects. In both places, micro-reliefs are classified in Verger's classification (1964) as types of isometric shapes without defined orientation (a^0).

However, in terms of height, width and distance between micromounds, the two sampling sites present statistically significant differences, demonstrated through the analysis of variance, the ANOVA statistical test. This indicates that despite having similar shapes, the size proportions and spacing patterns of the microreliefs found in each location are different, ruling out the hypothesis of homogeneous patterns of occurrence for the entire region where the locations are located.

There is little or no specific Brazilian literature on Gilgai microreliefs, which makes this work important as a source of data and preliminary observations on the subject. Other complementary works are necessary to better understand the patterns of Gilgai occurrence in Brazilian territory, being necessary more information about granulometric distribution, quantitative mineralogical analysis, contraction and expansion tests of its materials, among other analyzes that can elucidate questions still misunderstood on the genesis of these microreliefs in Brazilian soils.

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