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Dendrogeomorphology in Evaluating Erosive Processes in an Urban Conservation Unit

Dendrogeomorfologia na Avaliação dos Processos Erosivos em Unidade de Conservação Urbana

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Abstract

Water erosion is a worldwide problem that has been depleting soils mainly in tropical regions, due to the greater volume of precipitated water. In this sense, recent prediction methods in tropical regions such as dendrogeomorphology are necessary and important to identify and date the influence and correlation between erosion processes and vegetation. This study aimed to understand and scale the erosive processes, through the annual historical recognition of the rate of soil loss and sedimentation, applying the concepts of dendrogeomorphology in the evaluation of the stem and roots of trees of the species of *Anadenanthera macrocarpa* and *Schefflera morototoni*, in a conservation unit in the Brazilian Cerrado. Trees were selected in the following soil level conditions: (i) having root exposure, (ii) no exposure (buried), and (iii) no change in soil level (control). Cross-dating was performed using the COFECHA software program, and the information applied in dating scars and abnormal radial growth periods were observed in exposed roots and associated with the beginning of erosion processes. The results indicated that the occurrence of the erosive processes ascertained by anatomical changes in the exposed roots and a most common erosive rains date from 2006, 2008, 2009, 2010, 2012, 2013, 2016 and 2017. While changes in the trunk growth ring width start from 1992, with similar years between the two species of 2013 and 2017. The highest soil accumulation rates were 18.6 mm/year, vertical losses were 500 mm per year and horizontal losses were 665 mm. Finally, there is a positive correlation between the number of scars and an abrupt increase in the growth rings of the exposed roots with the number of erosive rains.

Keywords: Water erosion; Dendrochronology; Urban parks

Resumo

A erosão hídrica é um problema mundial que vem exaurindo os solos principalmente nas regiões tropicais, devido ao maior volume hídrico precipitado. Neste sentido, métodos de predições recentes nas regiões tropicais, como a dendrogeomorfologia, se apresentam como necessários e importantes para identificar e datar a influência e correlação entre processos erosivos e vegetação. Este estudo se propôs a compreender e dimensionar os processos erosivos, através do reconhecimento histórico anual da taxa de perda de solos e da sedimentação aplicando-se os conceitos da dendrogeomorfologia na avaliação do caule e raízes de árvores das espécies de *Anadenanthera macrocarpa* e *Schefflera morototoni*, em uma unidade de conservação no Cerrado brasileiro. Foram selecionadas árvores nas seguintes condições do nível dos solos: (i) com exposição radicular, (ii) sem exposição (soterradas) e (iii) sem alteração do nível dos solos (controle). A datação cruzada foi realizada através do *software* COFECHA e as informações aplicadas na datação de cicatrizes e de períodos de crescimento radial anormal, foram observados em raízes expostas e associadas ao início dos processos erosivos. Os resultados indicaram que a ocorrência dos processos erosivos, averiguados pelas alterações anatômicas nas raízes expostas, e a maior frequência de chuvas erosivas datam de 2006, 2008, 2009, 2010, 2012, 2013, 2016 e 2017. Enquantoalterações na largura dos anéis de crescimento do caule iniciaram a partir do ano de 1992, com anos similares entre as espécies de 2013 e 2017. As maiores taxas de acúmulo de solos foram de 18,6 milímetros por ano, as perdas verticais foram de 500 milímetros por ano e as perdas horizontais foram de 665 milímetros. Conclui-se que existe correlação positiva entre o número cicatrizes e aumento abrupto dos anéis de crescimentos das raízes expostas com o número de chuvas erosivas.

Palavras-chave: Erosão hídrica; Dendrocronologia; Parques urbanos

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1 Introduction

Water erosion, a natural process which depends on factors such as the climate, and mainly on rain events (intensity, duration and frequency), relief, physical and chemical attributes of the soil, and vegetation cover (Morgan 2005), is estimated at an annual cost of US$ 8 billion for global GDP, with a consequent decrease in global agri-food production by 33.7 million tons and an increase in water consumption by 48 billion m^3. In addition, the loss of fertile soils by erosion can reach around 35.9 billion tons annually due to anthropogenic activities around the world (Sartori et al. 2019).

The numerical methods for estimating soil losses have been questioned in the last decades due to the relatively small scales of approach (<10 years), and mainly with regard to problems related to climatic data, long-term field monitoring or detailed Digital Terrain Models (DTM), which are still absent in many areas (Kim, Ivanov & Fatichi 2016). Dendrogeomorphology is a subdivision of Dendrochronology, a science which assesses growth rings and morphological changes in tree wood, and stands out from traditional methods due to its more precise scale (annual) and its greater longevity for recording the magnitude of erosive processes and sedimentation (Ballesteros-Cánovas et al. 2013; Stoffel et al. 2013). Some studies on the effects of soil surface alteration on tree development in natural and man-made areas have indicated that both soil loss and sediment retention at the trunk base cause anatomical changes in tree wood and affect individual arboreal development, sometimes causing their growth to decrease (Strunk 1997; Ouden, Sass-Klaassen & Copini 2007; Jolley, Lockaby & Cavalcanti 2010). The soil loss in the roots and their consequent exposure causes an increase in width, a decrease or progressive increase of the growth rings, associated with eccentricity and injuries (scars) in the wood starting from the exposure date (Gärtner 2007; Bodoque et al. 2011; Corona et al. 2011). Thus, it is possible to identify the year that the roots started to experience soil losses.

However, further studies on the consequences of erosion in relation to plant growth in urban environments are still needed, since the speed of erosion processes can dramatically increase depending on the impermeable area and soil management (Morgan 2005; Bodoque et al. 2011). Much of the research on dendrogeomorphology focuses on temperate species and is mainly concentrated in alpine environments in Europe and North America, and in Argentine and Chilean Patagonia (Roig, Siegwolf & Boninsegna 2006; Stoffel & Bollschweiler 2008; Chartier et al. 2016). Despite this, research in tropical regions has identified high dendrochronological and dendrogeomorphological potential in tree species (Momoli et al. 2012; Venegas-González et al. 2017; Bovi et al. 2018; Bovi et al. 2019; Domínguez-Castillo et al. 2020).

In this context, this study aims to understand and dimension erosion processes through an annual historical recognition of the soil and sedimentation loss rate in an urban conservation unit in the central region of the Cerrado biome through dendrogeomorphological analysis. Moreover, to understand if there is a relationship between the erosive rains determined for tropical regions and the signs of changes in the growth ring width and the presence of scars in the roots exposed from water erosion located on the slopes with erosive features of the study area.

2 Materials and Methods

2.1 Study area

The Amália Hermano Teixeira Botanical Garden (JBAHT) study area is a municipal conservation unit surrounded by urban construction with the role of protecting water sources. It has a total area of 1.2 km² and is inserted in the southern portion of the municipality of Goiânia (State of Goiás, Brazil), between the coordinates 16° 43' 21.58" S and 49° 14' 54.44" W (Figure 1). The study area is a predominantly urbanized environment located in the Brazilian Cerrado with two well-defined seasons: a dry season which varies from May to September, and a rainy season from October to April. The mean total precipitation from 1964 to 2018 of the study area is 1610 mm/year. The rainy season has a monthly mean rainfall of 125 mm, with the highest rainfalls in the months of January and December with 250 to 260 mm. At the opposite extreme, the dry season averages about 30 to 50 mm. The temperature arranges from minimum of 14°C to maximum of 41°C, and average of 25°C. The vegetation of the study area consists of dense and closed forest, characterized as Seasonal Semi-deciduous Forest.

2.2 Species Selection and Site Description

The tree species selected for the study were: *Anadenanthera macrocarpa* (Benth.) Brenan (*Angico vermelho*) and *Schefflera morototoni* (Aubl.) Maguire, Steyerm. & Frodin (*Mandiocão*). Both have dendrochronological potential which has already been proven by other authors (Mendivelso et al. 2014; Nisgoski et al. 2014) and have wide distribution in the area. A total of 21 trees were selected and georeferenced (9 *A. macrocarpa* and 12 *S. morototoni*), according to the following soil level

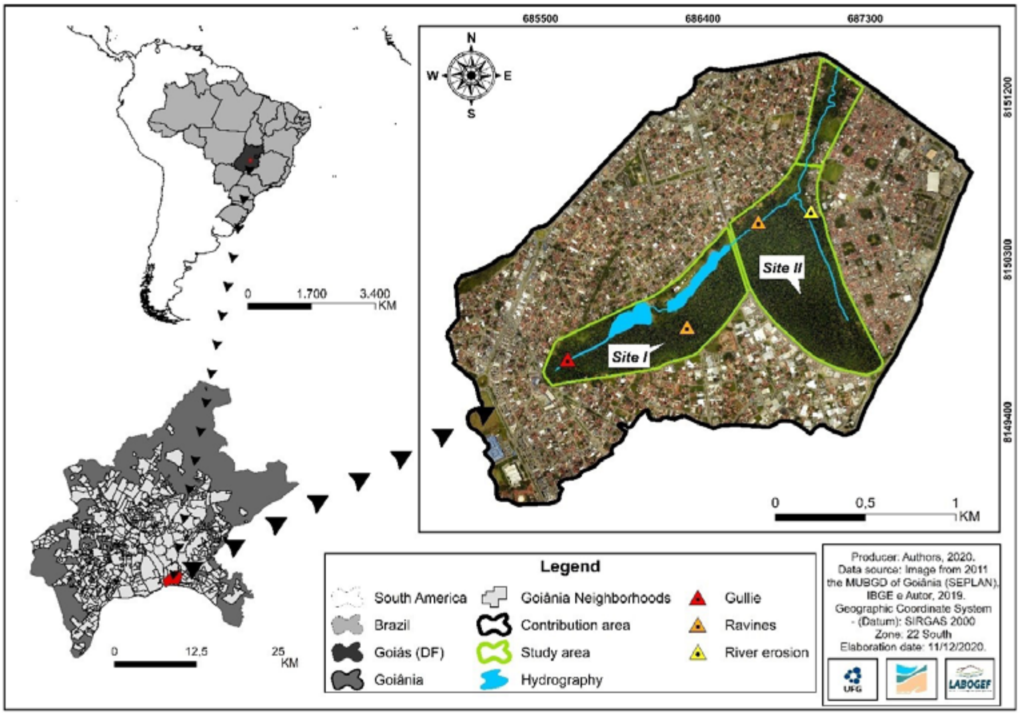

Figure 1 Location of the study area.

conditions: (i) showing root exposure, (ii) no exposure (buried), and (iii) no change in the soil level (control). There were two sites chosen within the study area for dendrogeomorphological analyzes: (i) Site I, which has a gully 10 to 12 meters deep and 16 meters wide; and (ii) Site II, with the presence of a slope on the banks of a water course enlarged by river erosion (Figure 1).

The erosive features were evaluated and classified *in loco*, according to their width and depth, as well as their respective coordinates, were recorded with Garmin Etrex GPS. The erosions in furrows are the smallest erosive features, generally classified with values lower than 50 centimeters, but this type of erosion was not found in loco, only ravines and gullies. In the study area, ravines with dimensions greater than the furrows were identified by the characteristic of the sum of several furrow channels and with a depth greater than 50 centimeters and a width of up to 3 meters. Gullies were classified with greater depth and width values than ravines and water table outcrop (IPT 1986; IPT 1999).

2.3 Trunk and root sampling

Two wood samples of 5 mm in diameter and up to 40 cm in length were collected from each of the 21 selected trees using a non-destructive method (increment probe) to perform dendrochronological analyzes.

Only trees presenting root exposure and no change in soil level conditions were sampled. Therefore, 3 samples of exposed roots were obtained in the same root segment, and another 3 samples from another segment of unexposed roots of the same tree located on the opposite side of the slope or the gully (Figure 2) using a saw, according to the methodology presented by Bodoque et al. (2011). The same sample number was considered when sampling tree roots presenting no change in the soil level (control).

A total of 21 *A. macrocarpa* root samples, 7 roots for each ground level condition and 34 *S. morototoni* root samples were evaluated, considering 10 to 13 roots for the different variations, represented in Figure 2.

All roots were sampled at least 50 (fifty) centimeters away from the trunk to avoid growth interference. The buried roots were removed at a depth of at least 15 centimeters from the soil level, as indicated and recommended by Gärtner (2007).

2.4 Estimation of Sediment Loss and Deposition

Vertical soil loss and the horizontal distance from neighboring roots were determined by measuring tape from the soil level portion to the upper portion of the root bark extracted *in loco*, according to the methodology proposed by Gärtner (2007), Bodoque et al. (2011), and Bovi et al. (2018) (Figure 3).

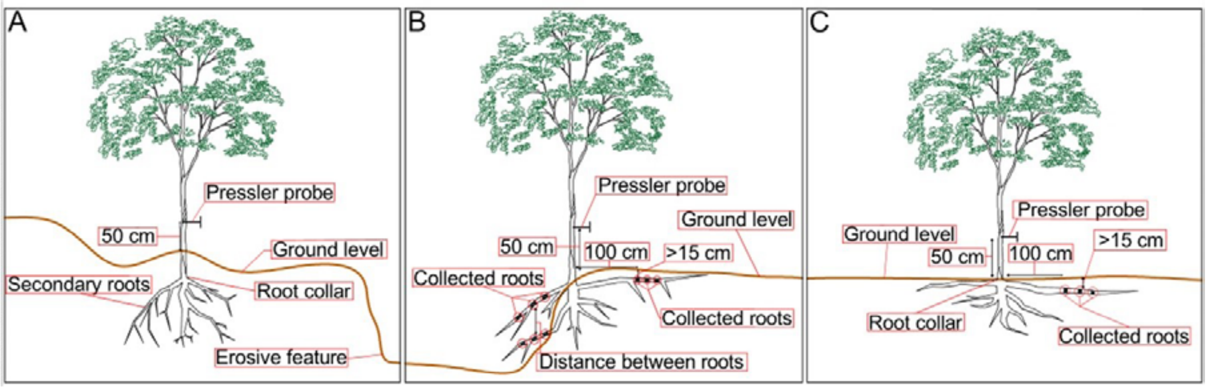

Figure 2 Schematic representation of the field procedure and tree sampling with: A. buried trunks; B. Trees showing exposed roots; C. Trees presenting no changes in soil level (control).

Figure 3 Collection and measurement procedures in *S. morototoni:* A. Vertical erosion rates; B-D. Measurement of the distance from roots parallel to each other (R1 and R2); C. Root with normal soil level (control individual).

The sediment thickness deposited at the trunk base was determined by locating the tree's trunk base, which marks the soil surface level at the germination time, or base level of 0 (zero) cm, used as a reference in identifying the sediment height (Hupp & Bazemore 1993).

2.5 Cross-dating of Trunk and Root Samples

The trunk cross-section and root samples were prepared in the first step by polishing, followed by identifying the anatomical pattern and demarcating the growth ring limit in a stereomicroscope and subsequent digitization (1200 dpi) of the samples. The growth rings were measured using the Image Pro Plus software program (version 5.0), with an accuracy of 0.001 mm.

Cross-dating was verified by the COFECHA software program, and samples with low correlation values with the master chronology were excluded from the chronology (Cook 1985; Grissino-Mayer 2001). A time series of trunk and root samples was generated in the ARSTAN software program (Holmes & Fritts 1986), excluding the natural tendency of radial growth of trees through detrending, and applying the negative and linear exponential models.

2.6 Determination of Annual Vertical Soil Losses

Annual vertical soil losses were determined by dating the beginning of the erosive processes using the information contained in the roots exposed on the slope of the erosive features, according to the methodology proposed by Gärtner (2007). Dimensioning the headland retraction rate of the erosive features, considered as horizontal erosion, was conducted according to the studies of Malik (2008), Domínguez-Castillo et al. (2020), and Bovi et al. (2019).

2.7 Erosive Rains

The number of erosive rains was correlated with the number of anatomical changes in the exposed root wood such as scars and the growth ring width in order to obtain greater precision in the years when soil water erosion occurred. The closest meteorological station, named National Meteorological Institute of Brazil (*INMET*), is located at coordinates, Latitude: -16.679124 and Longitude: -49.255422, 4.5 kilometers away from the study area.

To quantify the individual erosive rainfall, data were used, acquired by means of a Tipping Bucket Rain Gauge, which has a precision of 0.01 millimeters, with records and minute intervals. Located at Latitude coordinates: -16.713229 and Longitude: -49.258049, the 500 meters from the study area.

Next, the number of erosive rains in tropical regions was determined using the Hudson (1981) methodology, which considers rains greater than 25 mm h^{-1} as erosive. Thus, the number of individual erosive rains was quantified as those which contain rainfall greater than 10 mm at intervals of 15 minutes (Cabeda 1976; Wischmeier & Smith 1978). To do so, data acquired through a weighbridge pluviograph installed 500 meters from the study area was used. This device has an accuracy of 0.01 mm, with records and intervals in seconds from the 2011 to 2018.

3 Results and discussion

3.1 Anatomical Features of Growth Rings in Stem and Roots

The buried roots do not present scars on the wood and abrupt changes in the width of the growth rings, contrary to what is observed in the exposed roots of the analyzed species.*A. macrocarpa* roots have different growth layer limits with similar anatomical characteristics to *S. morototoni*, with the exception of the presence of marginal parenchyma (Figure 4C). Likewise, *S. morototoni* roots have different growth layer limits, as characterized by a slight decrease in vessel tangential diameter associated with tangential fiber wall thickening and the presence of marginal parenchyma (Figure 4F). Scar tissue is observed in roots which have undergone the root exposure process, associated with a significant reduction in the vessel diameter and an increase in their frequency (Figures 4A, 4B, 4D and 4E), eccentric growth and an abrupt increase in ring width. In buried roots, the diameter of the vessels in the early wood is larger than in the exposed roots, with a decrease in the frequency of vessels between early and late wood and an almost imperceptible increase in the vicinity of the marginal parenchyma. The anatomical characteristics of the stem of trees are similar to the roots (Figures 4G and 4H). The stems of individuals with root exposure are similar to those of exposed roots and buried stems have the same pattern as buried roots.

Scars are characterized by deformation in the wood tissue and are associated with growth disorders, whose size and frequency are controlled by the environmental conditions of the place, whether by relief, soil, vegetation cover, climate and anthropic changes (Gärtner 2007; Stoffel et al. 2013; Bovi et al. 2019).

Wounds and deformations in the exposed root bark usually occur due to the superficial water flow which transports sediments and debris, especially where there are higher slopes which can cause sufficient impact of these materials, thereby causing destruction of the root exchange and inducing scar formation (Stoffel & Bollschweiler 2008). This evidence was observed in all the exposed roots which were collected from slopes of 10% to greater than 15%.

3.2 Cross-dating Trunk and Root Samples

Cross-dating the species trunk samples showed high intercorrelation of values between the dated series belonging to the same species and the soil level condition, varying from 0.448 to 0.745 (Table 1), and verifying the annual growth ring formation (Figure 5) of the species. Furthermore, mean sensitivity values varying between 0.451 and 0.549 indicate that the species' trees are sensitive to environmental conditions.

The years highlighted by the arrows in the graph in Figure 5, show abrupt growth divergences in a given year between stem samples from buried and exposed conditions in relation to controls, so this evidence may be a possible signature of a process influenced by water erosion. In addition, these were dates with significant changes in land use around the park (Nicolau 2020). These sharp differences in growth, occur between the different treatments in the years 1987, 1996, 2001, 2005, 2007, 2009, 2012 and 2016 for A. macrocarpa (Figure 5A) and for the years 1963, 1980, 1986, 1991, 1993, 2001, 2005, 2012 and 2016 for S. morototoni (Figure 5B).

However, it is important to highlightlt that changes in growth patterns due to environmental changes do not always manifest themselves in the same year of the event, but 1 year after the date of the anthropic processes (Stoffel & Bollschweiler 2008), and therefore the most recent years of probable occurrences of the erosive process which affected the trunk growth of the evaluated *A. macrocarpa* trees were 1988, 1997, 2002, 2006, 2008, 2010, 2013 and 2017.

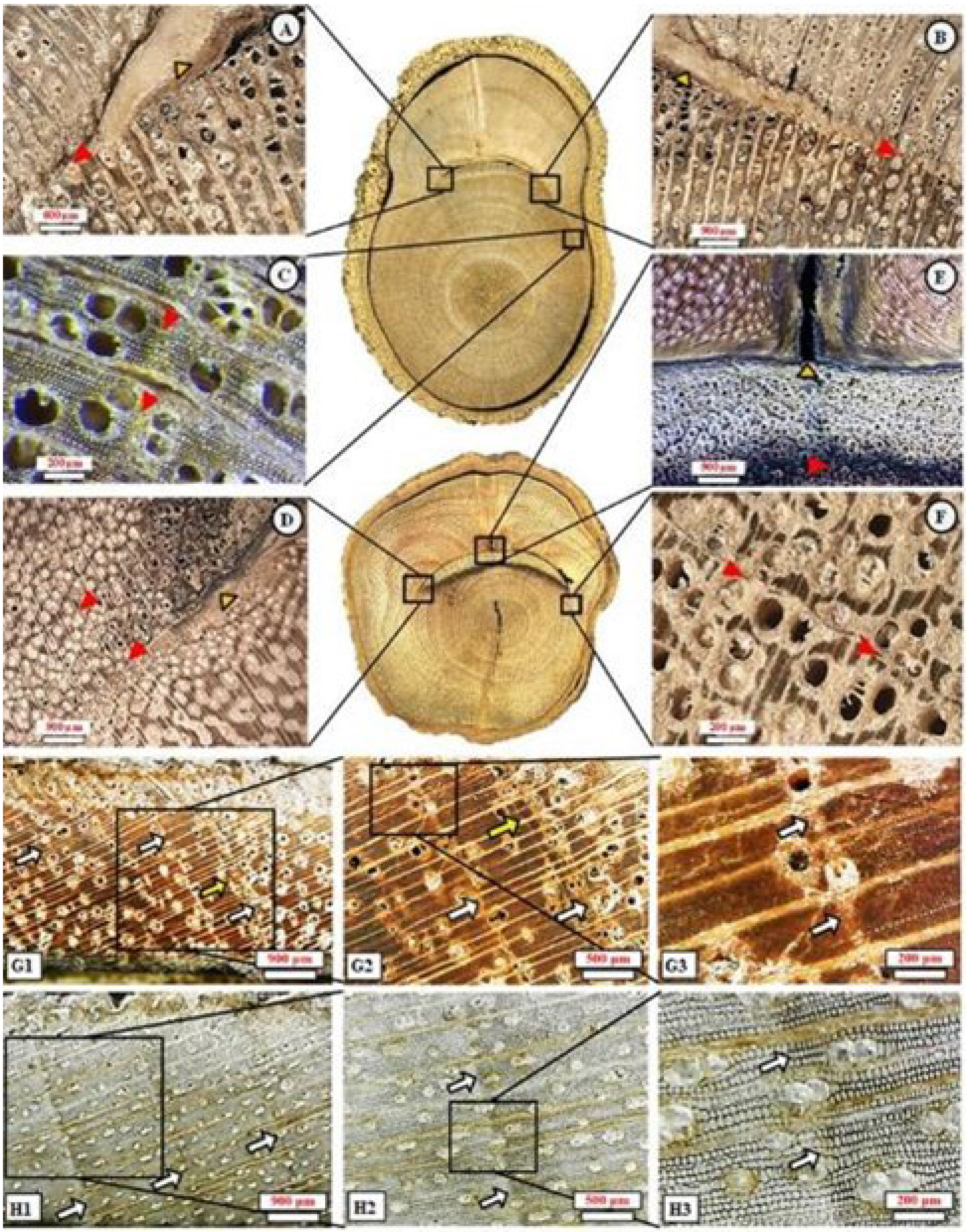

Figure 4 Examples of exposed roots with scars on the wood: A-C. *A. macrocarpa* showing evidence of root exposure in 2006; D-F. *S. morototoni* presenting root exposure beginning in 2014. Red arrows indicate the limit of the growth rings and orange arrows show the scars; Wood anatomical features on growth rings boundaries at different scales, respectively 900 µm, 500 µm and 200 µm of: G1-G3. *A. macrocarpa;* H1-H3. *S. morototoni.* White arrows indicate the limit of the growth rings and the yellow arrows indicate the fake rings.

Table 1 Chronological information of dated trunk series.

Species	Condition	Dated series (rays)	Series interval	Trees	Intercorrelation	Mean sensitivity
A. macrocarpa	Exposed	6	1969 to 2017	3	0.501	0.531
	Burried	6	1979 to 2017	3	0.482	0.549
	Control	6	1958 to 2017	3	0.728	0.539
S. morototoni	Exposed	10	1952 to 2017	5	0.448	0.457
	Burried	6	1955 to 2017	3	0.497	0.451
	Control	8	1938 to 2017	4	0.745	0.485

Critical correlation of 0.42*.

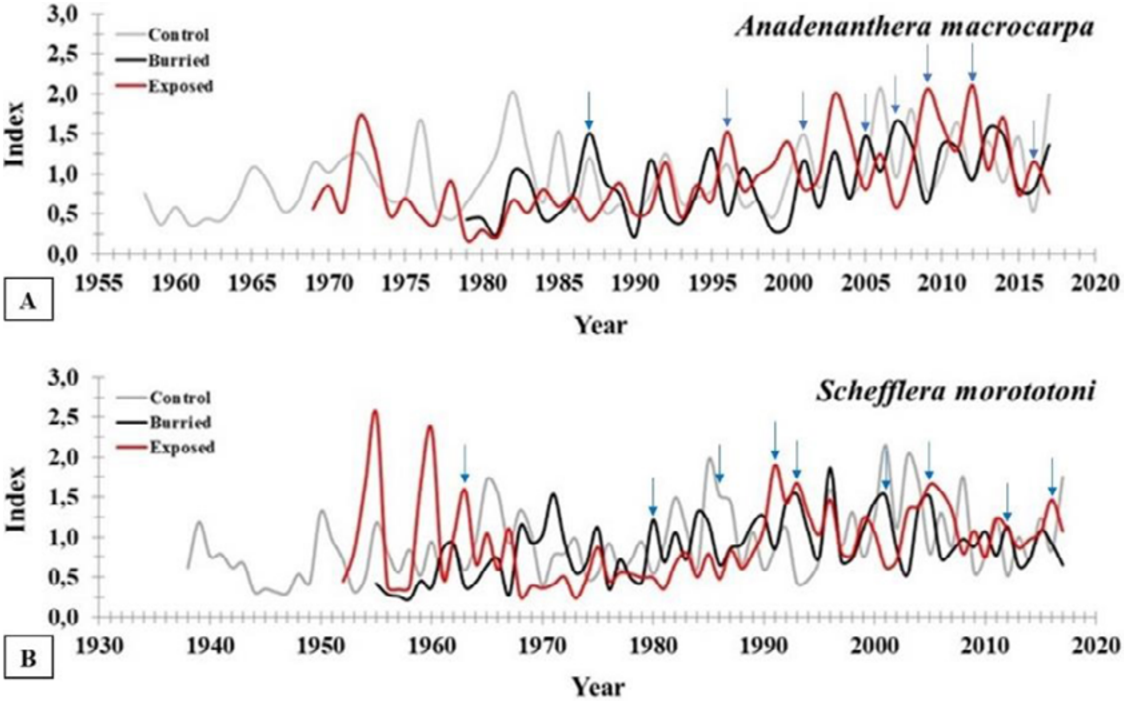

Figure 5 Growth ring chronologies on trunks from trees without changes in soil level presenting exposed roots and buried roots: A. *A. macrocarp; B. S. morototoni.* Blue arrows signify the years that there were abrupt differences in growth between stem samples from buried and exposed conditions compared to controls.

Evidence of water erosion recorded by the trunk growth ring width of *S. morototoni* occurred in the years 1964, 1981, 1987, 1992, 1994, 2002, 2006, 2013 and 2017. Of these, 2002, 2006, 2013 and 2017 were years which showed geomorphological processes in trunk samples of the two species and that may have a direct relationship with anthropic changes in the soil around forest sites.

The activities related to the history of anthropic changes in the study area surroundings which resulted in a significant increase in soil waterproofing occurred in the period between the years 1988 and 1992, with paving of public roads and a 30% increase in impermeable areas (1.31 km² of the study area). This in turn may have contributed to a significant decrease in water infiltration in the soil and increased runoff speed, thereby resulting in erosion and sedimentation processes. It is important to state that significant changes in soil waterproofing occurred from 2001 onwards, and was more frequently detected in the trunk samples of both species in 2005, 2012, 2016 and 2017 (Nicolau 2020).

The dendrochronological analysis of the roots indicated ages varying between 19 and 25 years for *A. macrocarpa* and between 14 and 19 years for *S. morototoni*, with synchronous growth between samples belonging to the same species and the soil level condition (Table 2). Intercorrelations varied between 0.516 and 0.622 and average sensitivity between 0.370 and 0.442.

Table 2 Chronological information of dated series of roots.

Species	Condition	Dated series (rays)	Series interval	Roots	Intercorrelation	Mean sensitivity
A. macrocarpa	Exposed	26	1995 to 2017	7	0.521	0.442
	Burried	28	1999 to 2017	7	0.543	0.398
	Control	28	1993 to 2017	7	0.622	0.429
S. morototoni	Exposed	51	2004 to 2017	13	0.516	0.370
	Burried	44	1999 to 2017	11	0.520	0.378
	Control	40	2000 to 2017	10	0.619	0.387

Critical correlation of 0.51*.

3.3 Chronology of Exposed Roots

The most likely years of water erosion occurrence indicated by abrupt variations in growth patterns detected in exposed roots compared to buried roots for both species are 1999, 2001, 2008, 2013, 2014 and 2015, as shown in Figures 6A and 6B.

The graphs in Figures 6A and 6B indicate the exposure years of the roots, considering the grouping (master series) of the information of each evaluated sample. Specialized literature (Gärtner 2007; Bodoque et al. 2011; Stoffel et al. 2013) recommends evaluating the information provided by each root separately to achieve greater precision in dating, as seen in the item 3.5.

3.4 Intense and Erosive Rains

The individual erosive rains are classified with amplitudes greater than 10 mm in an interval of 15 minutes (Cabeda 1976; Wischmeier & Smith 1978). In view of the results of this work (shown in Figure 7A), it is possible to state that the concentration of the number of these rains may be related to the number of scars or abrupt changes in the growth ring width, which is an important indicator of soil water erosion. It can be observed that the number of individual erosive rains and the erosion evidence on exposed roots are directly related, with emphasis on the years 2012, 2013, 2016 and 2017. The greatest black line inflections associated to scars were observed on the roots for these years.

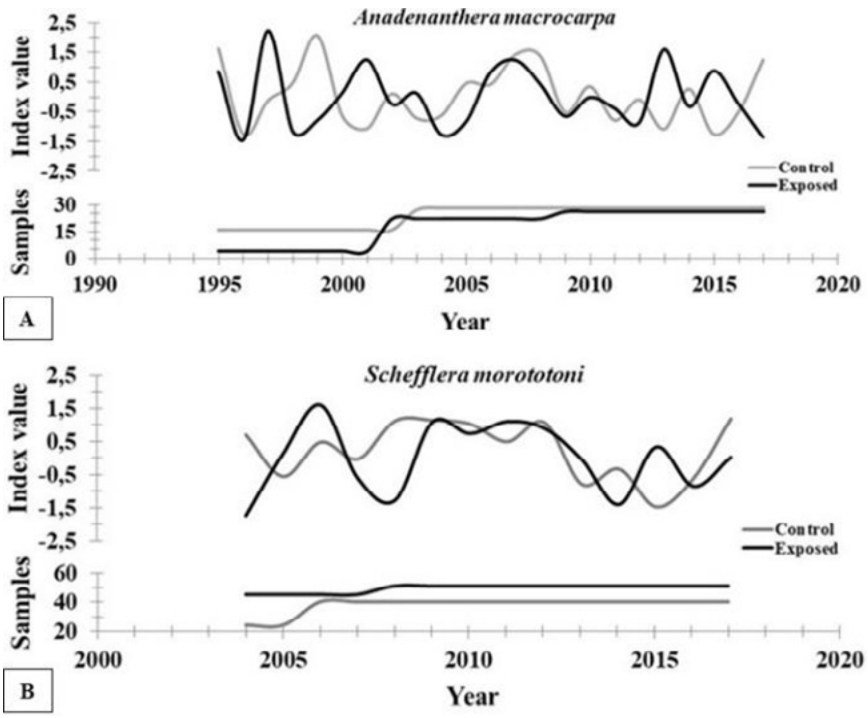

Figure 6 Master series of exposed roots, controls and respective sample numbers (radii) of: A. *A. macrocarpa; B. S. morototoni.*

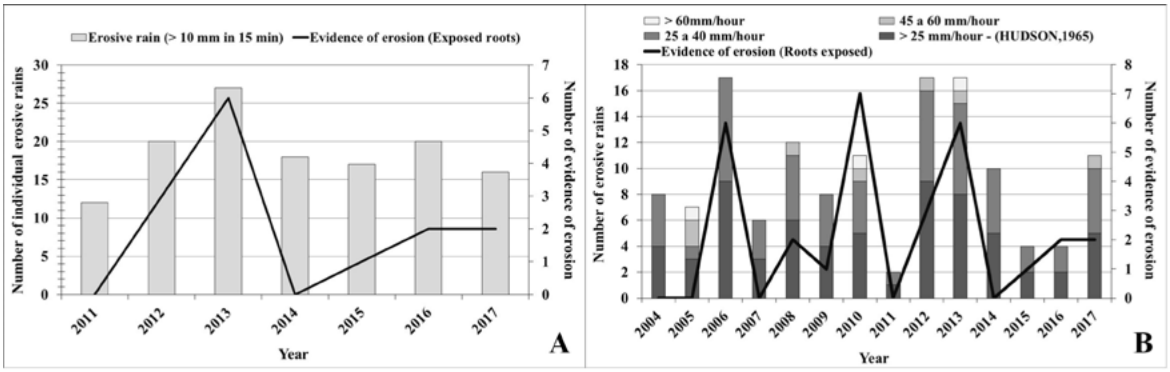

Figure 7 Number of erosions scarn on the exposed root wood and growth ring width related to: A. Individual erosive rainfalls; B. Number of erosive rains. Source: Tipping Bucket Rain Gauge and National Meteorological Institute of Brazil (INMET 2017).

Rains considered erosive in tropical regions (greater than 25 mm.h^{-1}) were evaluated and showed a high correlation of 0.7 in relation to the number of water erosions ascertained by the presence of scars and the growth ring width (Figure 7B). Rains of 25 to 40 mm.h^{-1} and 45 to 60 mm.h^{-1} showed correlations of 0.6 and 0.2, respectively, while rainfall greater than 60 mm.h^{-1} presented 0.5. There is greater synchronicity between the amount of erosion markings obtained through evaluating the roots and the number of erosive rains greater than 25 mm.h^{-1} (Figure 7B). The greatest black line inflection in the graph indicates the years with the greatest probability of the erosion process occurring, namely: 2006, 2008, 2009, 2010, 2012, 2013, 2016 and 2017. These years showed the greatest number of changes in the exposed root wood and more erosive rainfall. The results show that rains at 1-hour intervals have a greater potential for disintegrating soil particles at amplitudes greater than 25 mm.h^{-1} and over 60 mm.h^{-1}.

3.5 Estimation of Erosion and Sedimentation by Roots and Trunk

The study area is surrounded by an anthropogenic matrix with soil waterproofing in the upstream portion. It is believed that this fact may have led to the resulting vertical soil loss, which is to the order of 7 to 500 mm per year, and horizontal or backward losses of the erosion slopes range from 110 to 665 mm per year (Table 3). This information indicates that erosive processes in urban areas with high soil impermeability induce considerable soil losses. In turn, the erosive features in some years probably evolved with undermining and falling soil blocks from the upper edge of the head of the erosion process due to surface runoff and water course action which may have excavated and destabilized the slope base.

Erosion processes in the region identified as Site I of the study area are markedly more intense due to the proportions of the erosive feature considered as a gully because the vertical soil losses are higher, reaching 500 mm/year. The vertical erosion rates at Site II are lower at up to 230 mm/ year (Table 3). However, the horizontal water erosion rates at Site II regarding the widening progress in the erosion process are higher than Site I, totaling 665 mm/ year, probably due to the greater density of houses and lots and soil waterproofing. The occurrence years of the erosive process identified through anatomical signs in the exposed roots cover the years 2006 to 2017, with the most frequent years being 2006, 2008, 2010, 2012 and 2013 (Table 3).

The annual soil deposition rates at the tree trunk base (Table 4) were classified as very intense, as in the case of MAND 59 (*S. morototoni*) with the highest sedimentation thickness (1170 mm of sediment in 63 years or 18.6 mm/ year), to slightly intense such as ANG 40 (*A. macrocarpa*) with 250 mm of sediment in 39 years or 6.4 mm/year.

Sedimentation rates in tropical regions below that of this study (14.2 mm per year) were investigated by Momoli et al. (2012). Justifications for the observed differences are essentially based on characteristics such as the type of land use, since the study area herein presents major changes in soil waterproofing because it is located in an urban environment. The abovementioned author evaluated the sediment deposition in an agricultural environment in a similar condition. In addition, the area studied by Momoli et al. (2012) presents a very clayey soil texture, while a sandy soil texture was observed in the study area herein, which may have contributed to greater susceptibility to soil erosion (Brady & Weil 2013).

Other studies in tropical climate regions such as by Bovi et al. (2019) and Domínguez-Castillo et al. (2020) showed higher erosion rates than this work, with gully

Table 3 Sample number and vertical and horizontal soil loss rates recorded in the exposed root wood of *S. morototoni* and *A. macrocarpa* individuals.

Sample location	Species	Root ID	Dates of the roots exposures	Vertical soil loss in mm	Vertical soil loss in mm/year	Longitudinal distance between neighboring roots (mm)	Horizontal soil loss in mm/year
Site I - Gully slope	*A. macrocarpa*	A41- R1	2006	-490	44	–	–
		A41- R2	2006		44		
		A41- R3	2006		44		
	S. morototoni	M75 - R1	2010 and 2013	-710	113 and 177	330 and 600	110 - 200
		M75 - R2	2010		113		
		M75 - R3	2013		177		
		M54 - R2	2012	-650	130	320	320
		M54 - R3	2012		130		
		M62 - R1	2006 and 2009	-500	45 and 62	460	115 - 460
		M62 - R2	2010 and 2016		71 and 250		
		M62 - R3	2008 and 2016		55 and 250		
		M62 - R4	2010 and 2017		71 and 500		
		M62 - R5	2013 and 2017		125 and 500		
Site II - River erosion	*A. macrocarpa*	A50- R1	2013	-400	100	790	113
		A50- R2	2006		36		
		A34- R1	2013	-30	7	–	–
		A34- R2	2013		7		
	S. morototoni	M50 - R1	2010	-790	113	490	490
		M50 - R2	2010		113		
		M69 - R2	2008 and 2010	-460	51 and 66	1330	125 - 665
		M69 - R3	2006 to 2012		42 and 92		
		M69 - R4	2015		230		

vertical soil losses of 1,128 mm/year and horizontal of 2390 mm/year. The soil losses by the abovementioned authors were probably greater due to the soil texture in the study regions, which give greater susceptibility to erosion because they consisted of a sandy to very clayey transition with a textural B horizon (Brady & Weil 2013). However, the study environment in Bovi et al. (2019) and Domínguez-Castillo et al. (2020) is located in a peri-urban environment and has undergone minor waterproofing changes.

The study area we used is located in a tropical climate region where precipitation is more intense than temperate regions, and therefore water erosion is more accelerated. Studies carried out in temperate climates such as those by Pérez-Rodríguez, Marques and Bienes (2007), Bright and Boardman (2009), Chartier, Rostagno and Roig (2009), Bodoque et al. (2011), Corona et al. (2011), Saez et al. (2011), and Bollati et al. (2016), estimated soil losses of 2.4 to 275 mm/year, which results in soil losses of 2 to 19 times lower than our study area.

It is believed that the characteristics of the surrounding urbanization and especially the pluviometric index constitute the great differences in the soil loss rates with the abovementioned literature. This is because the soil loss rates of the above described authors are lower (varying

Table 4 Sediment deposition rates in millimeters per year and relationship with the age of the individuals.

ID	Scientific name	Soil deposition on the trunk (mm)	Age	Sediment deposition in mm/year
ANG 36	*A. macrocarpa*	200	26	7.7
ANG 39	*A. macrocarpa*	500	39	12.8
ANG 40	*A. macrocarpa*	250	39	6.4
MAND 44	*S. morototoni*	400	47	8.5
MAND 59	*S. morototoni*	1170	63	18.6
MAND 80	*S. morototoni*	600	35	17.1

from 3.5 to 8.8 mm/ year), despite other conditions of the physical environment such as a steeper slope ranging from 26 at 54% and soils which are naturally more susceptible to erosion such as the very sandy texture described in the works by Bodoque et al. (2011), Corona et al. (2011), and Pérez-Rodríguez, Marques and Bienes (2007), thereby providing greater natural vulnerability to soil loss compared to the study area.

The study area has different aspects from the abovementioned works such as a flatter relief with amplitudes of 8 to 20%, vegetation which is very dense, much higher mean accumulated precipitation with a total of 1610 mm/year, urbanization and intense waterproofing around the conservation unit with a total of 83% in 2016. Therefore, it is believed that precipitation and especially the characteristics of the surrounding urbanization constitute the major differences found in the soil loss rates by the abovementioned authors. It is important to note that the soil can generally be formed at a rate of 2.5 cm at intervals of 200 to 1000 years under natural conditions (Pimentel et al. 1995; Brady & Weil 2013). However, soil loss rates reach 66.5 cm per year in the study environment, thus making it clear that the erosion process speed is accelerated by anthropic action.

In view of the specialized literature, the erosion process speed in the study area is often more expressive than in the temperate climate due to soil losses of 500 to 660 mm/year. Thus, it is important to reinforce that the erosive features are accelerated by the anthropic action of urbanization around the study area and can be enhanced by the intense rains which are characteristic of tropical regions. Finally, despite the few existing works of dendrogeomorphology in the Brazilian Cerrado and mainly in conservation units inserted in an anthropic environment, it is noticed that the soil loss in these environments possibly has a higher speed than less urbanized areas.

4 Conclusions

This work brings an innovative proposal for studies on erosion in the Brazilian Cerrado in an anthropic environment and using *Anadenanthera macrocarpa* and *Schefflera morototoni* tropical species which are widely distributed in Brazil and establishes a cause-and-effect relationship of the speed of erosion processes in a conservation unit. *Anadenanthera macrocarpa* and *Schefflera morototoni* individuals from the Botanical Gardens study area have annual growth rings and have the potential to be used in dendrochronological and dendrogeomorphological studies. Dendrogeomorphological analyzes of the species responded with important anatomical variations such as abrupt ring growth in the first year of exposure associated with the presence of scars on the slopes of the erosive features.

The soil and sedimentation loss rates conducted by dendrogeomorphology make it evident that water erosion has an accelerated speed, and the most likely causes are anthropic changes in the surroundings, inadequate soil management and erosive and torrential rains, which are typical of tropical climate regions. Significant correlations were obtained between the number of erosive rains with an interval of 1 hour and those of 15 minutes with the number of anatomical changes such as scars and abrupt growth changes in the exposed root wood. Therefore, it is concluded that there is synchronicity in the anatomical changes and in the growth ring width between the exposed roots and trunk, as well as the erosive rains, with a temporal distribution pattern for the years of 2006, 2008, 2010, 2013 and 2017.

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Ricardo de Faria Nicolau: conceptualization; formal analysis; methodology; validation; writing-original draft; writing – review and editing; visualization. **Karla Maria Silva de Faria:** review and editing; supervision. **Renata Santos Momoli:** conceptualization; writing review and editing; supervision. **Matheus Peres Chagas:** validation; writing review and editing.

Conflict of interest

The authors declare no potential conflict of interest.

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All data included in this study are publicly available in the literature and cited in references. The resulting model, scripts and code are available on request.

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