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Geographic Information System applied to Forest Management in the Miombo Forest Polygon in Cambiote (Huambo, Angola)

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ABSTRACT

This paper aimed to study the applications of Geographic Information System in forest management in the Miombo forest polygon in Cambiote (Huambo). The survey was carried out between October 2019 and August 2020. Data collection was carried out in two stages: geospatial data (NDVI, land use, administrative boundaries) on web servers (United States Geological Survey, European Space Agency, Map library); traditional forest inventory data that included geoprocessing applications and techniques. In this stage, three rectangular sample plots measuring 25 x 20 m (500 m2) were marked and georeferenced. The results showed that geoprocessing techniques in forest management help in locating plots and understanding their spatial distribution within the Miombo forest and their floristic composition, clearly showing the occurrence of species through the maps. The analysis of forest inventory data from a dendrometric and spatial perspective allowed the study of a population of 212 individuals, with emphasis on the species *Ochna schweinfurthiana* with 54 individuals, *Brachystegia boehmii* 66 and *Parinari curatellifolia* 31. The average basal area per hectare was 0.7, the average volume per hectare was 1.7 and the average number of individuals per hectare was 140. The analysis in the spatial perspective showed greater spatial distribution, in the study area, of these species. Therefore, it was recommended that further studies be carried out on the spatial distribution of Miombo woodland species, in order to guarantee the conservation and sustainability of species with high energy, edible, medicinal and other values.

Keywords: GIS, Forest management, Forest inventory, Miombo woodland.

RESUMO

Este estudo visou estudar as aplicações dos Sistema de Informação Geográfica no ordenamento florestal no polígono florestal do Miombo no Cambiote (Huambo). A pesquisa foi realizada entre Outubro de 2019 e Agosto de 2020. A colecta de dados foi feita em dois momentos: dados geoespaciais (NDVI, uso de solo, limites administrativos) nos servidores web (United States Geological Survey, European Space Agency, Map library); dados de inventário florestal tradicional que contemplou aplicações e técnicas de geoprocessamento. Nesta etapa foram marcadas e georreferenciadas três parcelas amostrais rectangulares de 25 x 20 m (500 m2). Os resultados mostraram que as técnicas de geoprocessamento no ordenamento florestal auxiliam na localização das parcelas e compreensão da sua distribuição espacial dentro da floresta de Miombo e a sua composição florística mostrando claramente a ocorrência das espécies através dos mapas. A análise dos dados de inventário florestal na perspectiva dendrométrica e espacial, permitiu estudar uma população de 212 indivíduos, com destaque as espécies Ochna schweinfurthiana com 54 indivíduos, Brachystegia boehmii 66 e Parinari curatellifolia 31. A área basal média por hectare foi de 0,7, o volume médio por hectare foi de 1,7 e o número médio de indivíduo por hectare foi de 140. A análise na perspectiva espacial mostrou maior distribuição espacial, na zona de estudo, destas espécies. Assim recomendou-se que se realizem mais estudos de distribuição espacial das espécies do Miombo, visando garantir a conservação e sustentabilidade de espécies de alto valor energético, comestível, medicial e outros.

Palavras-chave: SIG, Ordenamento florestal, Inventário florestal, Miombo.

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1. Introduction

Forests are essential for the well-being of humanity. It forms the foundations for life on earth through ecological functions, the regulation of climate and water resources and serves as a habitat for plants and animals. Forests also provide a wide range of essential goods, such as wood, food, fodder, medicine, as well as opportunities for leisure, spiritual renewal and other services. Today, forests are under pressure due to increased demand for land-based products and services, which often results in forest degradation or transformation into unsustainable forms of land use. When forests are lost or severely degraded. Their ability to function as regulators of the environment is also lost (Pughet al., 2019; Yoshimoto et al., 2016).

The result is an increased danger of flooding and erosion, a reduction in soil fertility and the disappearance of plants and animals. As a result, the sustainable supply of goods and services from forests is jeopardized (Branthomme et al., 2009).

Due to the character of the personnel who plan the Forestry Planning and given the systematic condition of the forests, the diversity of utilities they offer and the economic and social influences of their management; The necessary data strip is complicated and must be rigorous. The complexity of this first stage of Forest Management, known as the Inventory or Inventory for Forest Management, has increased, from the first projects carried out in 11th-century Europe, in which the inventory was nothing more than a simple assessment of wood and firewood, to our days (Osório, 2018).

For Pughet al. (2019) and De Pellegrin Llorente et al. (2017), forest management is the set of integrated measures of a legal, administrative and technical nature, which aim to determine the location, classification, organization and sustainable management of forests. Forest management measures must be based on forest inventories.

In turn, Yoshimoto et al. (2016) and De Pellegrin Llorente et al. (2017), state that the Regional Plans for Forest Management are instruments of sectoral policy, which focus on forest areas and aim to frame and establish specific rules for use, occupation, utilization, and forest management, in order to promote and guarantee the production of goods and services and the sustainable development of these spaces.

Since Geographic Information Systems (GIS) have the possibility of incorporating the spatial component in land use planning and simulation models, the development of links between forest models and GIS provides forest managers with greater flexibility in determining the productivity of species and their requirements, and allows policy makers an increased opportunity to assess the effects of alternative forest management criteria (Tiwari et al., 2021; Paulino, 2008).

Public policies for the forestry sector have been implemented since the country's independence in 1975, with a view to mitigating climate conditions and restoring and conserving the vegetation cover through intense tree planting activities associated with soil protection, conservation of water and regularization of the hydrological regime, in the search for the balance of ecosystems and environmental restitution. Currently, Cape Verde's forestry policy defined in the National Agricultural Strategic Plan continues the fight against desertification, but now, directing it towards population participation and sustainable management of forest and agro-silvopastoral resources (Moreno, 2009).

In Angola, the contribution of the forestry sector to the subsistence economy is much greater than its role in the formal economy. The official Gross Domestic Product (GDP) statistics still do not actually reflect its contribution to the country's economy (Bahu, 2015).

According to Bahu (2015), in Angola forestry is not yet carried out under a sustainable income regime. The areas under forest exploitation do not have a management plan and the State's ability to monitor logging activities is quite weak. This jeopardizes the maintenance and renewal of these important resources. Circumstantial exploitation persists, focusing on the exploitation of wood under simple licenses, which encourages selective exploitation, causing little appreciation of a large number of woody forest species that are little promoted in the market.

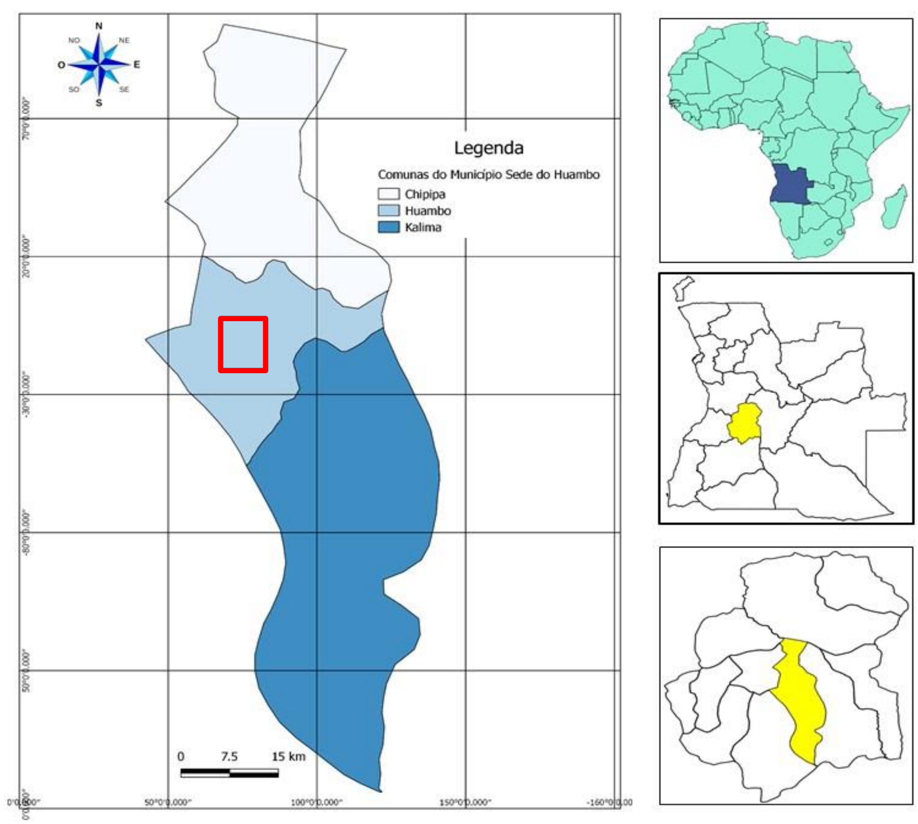
The Government of Angola recognizes in its document on the Strategy to Combat Poverty, the importance of the forestry sector in the country's socio-economic development process and, in particular, in integrated rural development, given its multidisciplinary characteristic, capacity to produce goods destined to meet basic needs, have a high capacity to absorb labor and contribute to the food security of populations (MA & UNCCD, 2018; Ambiente, 2009). The concepts and arguments exposed above allowed us to study the applications of the Geographic Information System in Forest Management in the Miombo Forest Polygon in Cambiote (Huambo).

2. Material and methods

2.1 Characterization of the study area

The study was carried out between October 2019 and August 2020, in sample plots (3 plots of 25 x 20 m each, that is, 500 m2 each) located in Cambiote, north/south/east/west of the city of Huambo/Angola, is located between the following geographical coordinates: 12° 46' 00" S and 15° 44' 00" E. The area, like the city, is more than 1300 meters above sea level, however a large part reach altitudes above 1700 meters. It is the capital city of the province that bears the same name, founded in 1912 and later, in 1929, called Nova Lisboa (Mendelsohn and Weber, 2013). See figure 1.

Figure 1- Location of the study area



Source: Authors (2020)

The municipality, where Bairro Cambiote is located, has an area of 2,609 km² (26.09ha) and about 665,000 inhabitants (INE, 2016), is limited to the north by the municipality of Bailundo, to the east by the municipality of Tchicala-Tcholoanga, to the south by the municipality of Chipindo, and to the west by the municipalities of Caála and Ekunha. It comprises the communes of Chipipa, Huambo and Kalima.

The soils of the municipality of Huambo are generally of the Ferralitic type, red in color and with a pH that varies between 5.3 and 6.2; it has a low content of organic matter (OM), low cation exchange capacity, higher in the A horizon (surface) and with low levels of Nitrogen, Phosphorus and Potassium (Madeira and Ricardo, 2015). They are normally thin, distinguished by their very intense red color, great friability and lack of structure (Diniz et al., 1996). Although the soils of these groups are generally deep and friable, however, they present laterites or lateral materials at less than 1 m depth (Sardinha, 2008). The absence of nutrients results in the constant use of chemical and organic fertilizers, which over time causes soil acidity and causes a reduction in agricultural production capacity (Russo, 2007).

It has extensive forests, predominantly native to medium-sized trees and plantations of xerophilous and exotic species such as *Eucalyptus sp*., *Cedrus sp.* and *Pynus sp*. forest perimeters, in addition to many edible, medicinal, ornamental and wild fruit plants much appreciated by local populations. Its fauna is quite diversified with relief for large, medium and small animals. The vegetation of the municipality of Huambo is of the Miombo woodland or panda forest, a typology where trees belonging to the genera *Brachystegia*, *Isorbelinia* and *Julbernádia* predominate (Quissindo, 2018). This forest formation is the main type in Angola, occupying about 45.2% of the total forest area, dispersing over vast areas of the country, including the Central Plateau provinces (Bié, Benguela, Huambo and Huíla), as well as Kuando Kubango, Moxico, Malanje and Kwanza-Sul (Sangumbe et al., 2014).

The climate is dry, moderate or rainy, depending on the average annual temperature, the annual average relative humidity, the variation of the diurnal temperature amplitude and/or precipitation (Malengue et al., 2018). It is the second highest and coldest city in Angola after Lubango which is to the south of it and which is a little higher than it being 2 degrees south of Huambo. It is located on a plateau above 1,774 m in altitude and has a Tropical Altitude climate (Cwb) or Oceanic Climate (Cwb). Characterized by humid and warm summers, with mild nights and relatively warm days and dry winters with mild days and relatively cold nights. The province in general and the city has an alternating wet and dry climate influenced by altitude, the average annual temperature is 19ºC, with a minimum of 15ºC and a maximum of 20ºC, marked by two seasons (Delgado et al., 2007).

2.2. Data collection and methodology

2.2.1. Geospatial data: collection and methodology

In a first phase, the geospatial data processed and analyzed were acquired from the following web servers:

- United States Geological Survey (USGS) for Landsat 8 imaging;
- European Space Agency (ESA) Copernicus Open Access Hub for downloading land use data;
- Map library for downloading vector data with administrative policy division information;
- International Research Institute for Climate and Society (IRI) and Lamont-Doherty Earth Observatory (LDEO) to acquire information on vegetation index.

Next, a brief characterization of the servers described above is made. For Dala et al. (2018) Maplibrary is a public domain African geospatial database that contains useful information for the geographic location of zones on the continent from communal to continental administrative levels. In turn, Drusch et al. (2016) describes the Earth Explorer (United States Geological Survey - USGS) data portal as a geospatial data provider for the entire globe of the United States Geological Survey that provides information such as: Landsat satellite images, radar data, UAS, Digital Line Charts, Digital Elevation Model Data, Aerial Photos, Sentinel Satellite Data, some commercial satellite imagery including IKONOS and OrbView3, land cover data, National Map digital map data, and many other sets of data.

Tona and Bua (2018) indicate the Copernicus Open Access Hub (formerly known as Sentinels Scientific Data Hub) as the European Space Agency's global geospatial data provider providing full, free and open access to Sentinel user products -1, Sentinel-2, Sentinel-3 and Sentinel-5P, from the In-Orbit Commissioning Review.

And the IRI and LDEO are presented by Torlay and Oshiro (2010) as a provider of geospatial information useful in vegetation monitoring.

However, based on data and remote sensing techniques, the Normalized Difference Vegetation Index (NDVI) or Normalized Difference Vegetation Index was calculated (Palácios et al., 2015), which is a useful indicator in the analysis of presence or absence of vegetation, biomass and photosynthetic activity. See illustration in figure 5.

This calculation was performed using the Quatum Gis software version 2.18, with the help of Google Earth Pro version in the data preparation.
The formula used to calculate this index is the constant below (Jensen, 1996):

$$\mathrm{NDVI} = (\mathrm{NIR} - \mathrm{Red}) / (\mathrm{NIR} + \mathrm{Red})$$

Where:
NDVI - Normalized Difference Vegetation Index;
NIR - Reflectance at the wavelength corresponding to Near Infra-Red (0.76 to 0.90 μm);
Red - Reflectance at the wavelength corresponding to Red (0.63 to 0.69μm).
The index, which ranges from -1 to 1, is a useful indicator in biomass analysis and vegetation monitoring.

2.2.2. Traditional forest inventory data: collection and methodology

The experimental design that led to the collection of data in the field was in randomized blocks, because it allowed that from an initial point a plot was marked and thus the others were systematically marked.

Stratified sampling was used as it has the advantage of allowing the study area to be divided into three plots or target zones with an area of 500 m² for each.

The perimeter of the forest polygon under study is 857 meters and it occupies an area of 7,062 m2 (0.7 ha). The sample zones occupy an area of 1,500 m2 (0.15 ha), which represents 21% of the total forest area under study. The establishment and size of the sampling plots were based on previous studies carried out in the Miombo forest and which addressed sampling sufficiency for the Miombo forest: Hofiço (2014) in Mozambique; Cachenhe et al. (2018) and Quissindo and Cachenhe (2021) in Angola.

In the meantime, data collection was also carried out through an inventory to collect dasometric data that allowed to know the current state of the plots under study; In addition, geographic coordinates were extracted for each species per individual, which allowed for the elaboration of distribution maps of the species that occur in the plots.

The planning of the experimental design for carrying out the adapted inventory that included geolocation was as follows:

- Marking of 3 (three) rectangular sample plots;
- Size of each sample: 25 x 20 m (500 m2);
- Samples were taken systematically (every 5 m) to avoid the edge effect (edge) and tree-free zones;
- During plot marking, the geographic coordinates of the central and extreme points were extracted.

The data acquired in the field can be seen below in table 1 (which was filled in during the inventory activity).

Through the association of geospatial data and traditional inventory, the pattern of distribution of individuals by species, diameter and height classes was determined. This pattern was determined based on the classical methodological proposals of Currie and Paquin (1987), which does not use techniques and methods based on geotechnology and the modern method of Valverde-Barrantes et al. (2018), which uses technological resources of science and observation of the earth and its resources.

Thus, the same dasometric data (obtained through an inventory) were introduced and analyzed with the aid of the inventory data processing database of the Center for Tropical Ecology and Climate Change

(CETAC), as shown in figure 2.

The tool is proprietary software developed with a view to creating applications (based on scientific innovation and technological incorporation foundations) to support the collection and detailed treatment/processing of forest inventory data in Angola and beyond, in order to propose silvicultural measures, suitable for the forest or forest polygon of interest (CETAC, 2020). See table 1.

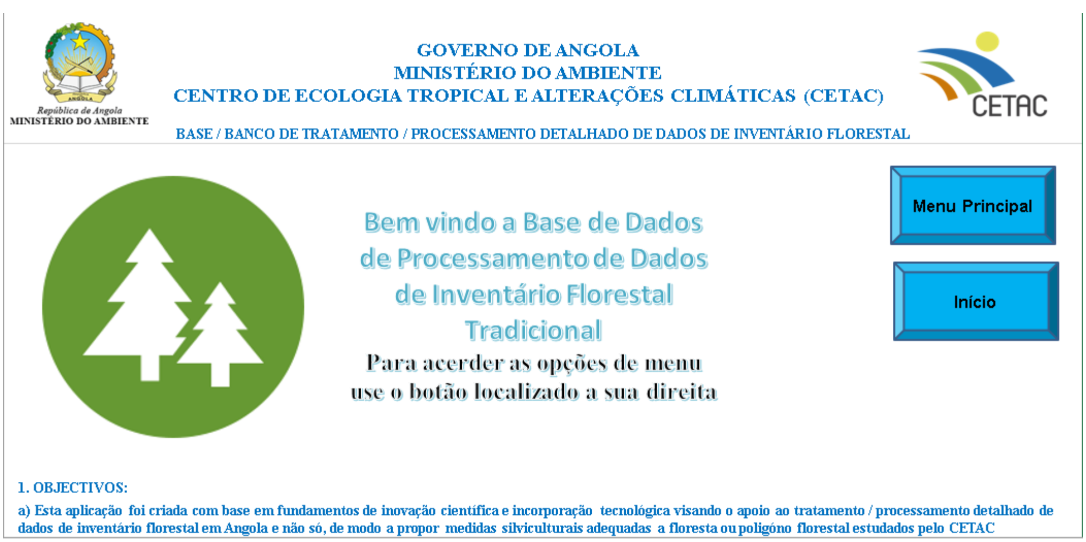
Table 1- Forest Inventory Data Collection Form

Installment No. _______________				
Geographic coordinates of points				
Central point Latin: ________________ Long:________________			Extreme points 1, 2, 3 and 4 Latin: _______________ Long:_____________	
Dasometric data				
Tree species				
DBH (cm)				
Height (m)				
Age years)				
Shell thickness (cm)				
Average diameter of the branches (m)				
Individual's geographic coordinate				

Source: Authors (2022)

The tool (figure 2) is prepared to analyze data obtained in the field with the help of open source android applications (on mobile phones) such as ODK Collect and KoBo Collect in the form of a questionnaire to collect forest inventory data (CETAC, 2020).

Figure 2- Forest data processing database interface



Source: Authors (2021)

However, for the present work, the variables and parameters calculated are: diameter of the normal section, density, height, basimetric area, biomass and volume); in addition, in the absence of LiDAR remote sensing data, the geographic coordinates of each individual were extracted with a Garmin etrex 20x GPS device.

In a logical and sequential manner, the variables and parameters calculated are as follows:

A) Diameter of the normal section (Dn)

Within each sample plot, the normal section of the diameter at 1.30 m in height (Dn) of all the inventoried trees (dn ⩾ 2.5 cm) was determined using a Haglof "Mantax Black" forceps with nailable jaws (I = 650 mm).

B) Density

Tree density, defined as the number of individuals per unit area, was determined for all species found in the 3 (three) sampling plots. The objective was to identify the number of the main species present in the study areas.

Height of trees (Ht)

In the 3 (three) sample units of study for trees with Dn ≥ 2.5 cm at 1.30 m in height, the height measurement was performed with the Clinometer device, which allowed the height to be accurately measured, with the aid of a self-sight at a fixed distance from the tree to the observer equal to or greater than the height of the tree.

Species identification

In each sample unit, the species found were identified, having been identified with the aid of the dichotomous key proposed by specialists who studied the Angolan Miombo woodland ecosystem (Diniz, 2006; Sanfilipo, 2014) by their local name in Umbundu or Vulgar language and by the scientific names.

C) volume determination

The volume of wood was estimated based on the basimetric area at a height of 1.30 m, using the following formula:

Wood volume (m3) = π / 4 x Diameter2 x Height x Fe.

Where Fe is an empirical form factor and in Miombo woodland species it must be between 0.36 for heights above 12 meters and 0.39 for heights below 12 meters.

D) Determining the thickness of the shell

The bark thickness was determined by opening a hole in the trunk of the tree with the help of a needle graduated up to 10 cm. The use of a needle is due to the fact that it reduces the number of injuries that could be made on the inventoried trees if larger equipment were used.

E) Determination of the length of the branches (cm)

To determine the length of the branches, the three largest branches of each tree were selected and the height of each one was measured with the help of a tape measure and then the same values were added, finally finding an average, the height of the branches of each tree.

F) Determination of the crown diameter (cm)

This variable was measured using a tape measure from the south end to the north end and from the east end to the west end; then, the average of these values for each tree was found.

However, the spatial distribution of species, their diameter and height, made in this work was based on the classic study by Young and Young (1998), which presents the parameter "exponent k" as a good dispersion index when the size and numbers of sample units per sample are the same, as this index is often influenced by the size of the sample units. This parameter is an inverse measure of the degree of aggregation, and negative values indicate a regular or uniform distribution. Positive values close to 0 indicate aggregate disposition and values greater than 8 indicate random disposition. When $0 < k < 8$, this index indicates aggregate distribution, and when $0 > k > 8$, it points to random distribution. The authors point out the following internal distribution patterns: random (random), uniform (regular) and aggregate (contagious).

3. Results and discussion

Since the study integrates field and geospatial data, it follows, in a systematic and logical way, the results with the respective topics where each of the analyzes appears, whether based on traditional inventory data or remote sensing techniques.

3.1 Spatial Distribution of Forests in the Municipality of Huambo

The first two results are a consequence of the analysis of satellite images, as described in the methodology. However, because the plots have reduced areas, for study with free satellite images of medium spatial resolution, the NDVI calculation and the analysis of the land use and occupation classes in the municipality of Huambo were not only the plots, but of the municipality of Huambo as described below.

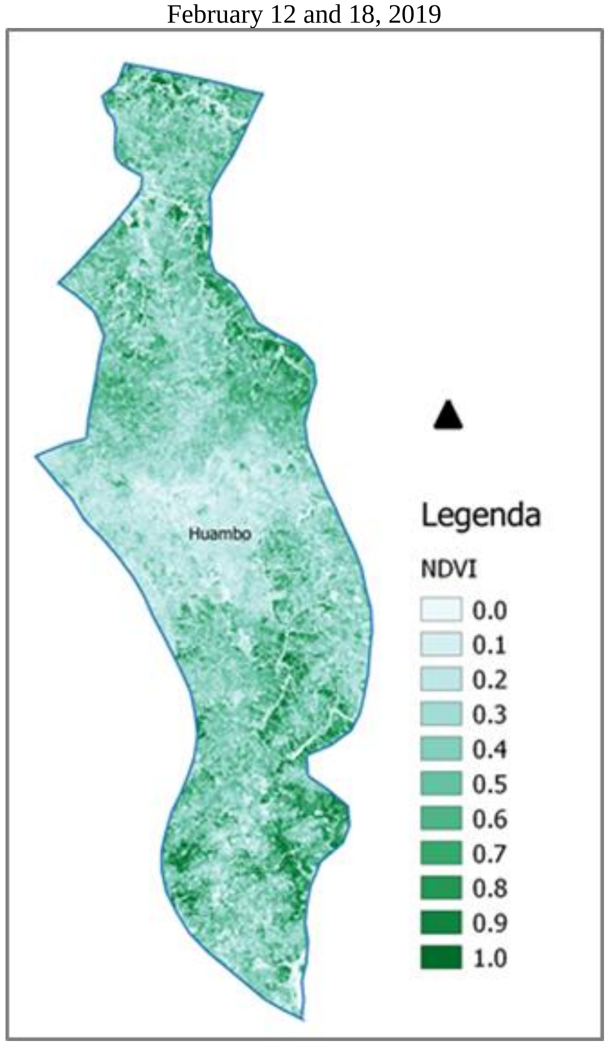
3.1.1 Normalized Difference Vegetation Index of the municipality of Huambo

The Normalized Difference Vegetation Index (NDVI) calculated allowed us to conclude that in the municipality of Huambo, both in urban areas and in peripheral rural areas, the low value of this index is associated with the absence of vegetation (either by conversion of forested areas into urban areas or the existence of vast areas with bare soil or vacant land), which associated with topographic and precipitation factors favor the emergence of erosion.

Some studies support this idea, considering that forest degradation and deforestation in the central highlands, in general, and in the province of Huambo, in particular, are essentially linked to the expansion of the agricultural area and the production of charcoal, due to the great concentration of timber species in the Angolan Miombo woodland (Schneibel et al., 2017; Chiteculo et al., 2019; Miapia et al., 2021; Quissindo et al., 2021; Cabral et al., 2010; Palacios et al., 2016), a practice that has led to an increase in soil erosion conditions.

Thus, the visualization of the state and presence of vegetation by the NDVI in the target zone (figure 3) clarifies the absence or existence of deficient vegetation in the zone.

Figure 3- Normalized Difference Vegetation Index of the municipality of Huambo for the period between February 12 and 18, 2019



Notwithstanding this, it is also noted in the map in Figure 6 that there is a considerable surface covered by medium and high values of NDVI (0.7 – 1), which is associated with the existence of Miombo forests, which predominate in this region. zone, in addition to agricultural land with crops in growth phase (0.3 – 0.7); this idea is based not only on a geospatial interpretation, but also on a temporal one, since the image processed for the NDVI analysis has the date captured by the Landsat 8 LDCM sensor corresponding to the end of the rainy season (12-18 February 2019).

The index showed the presence of sparse vegetation in suburban and urban areas, where low to medium NDVI values are dispersed (0.1 - 0.5), which shows the existence of vegetation in these areas (urban afforestation and forest masses for environmental and urban areas, for example the famous Estufa Fria in the city centre).

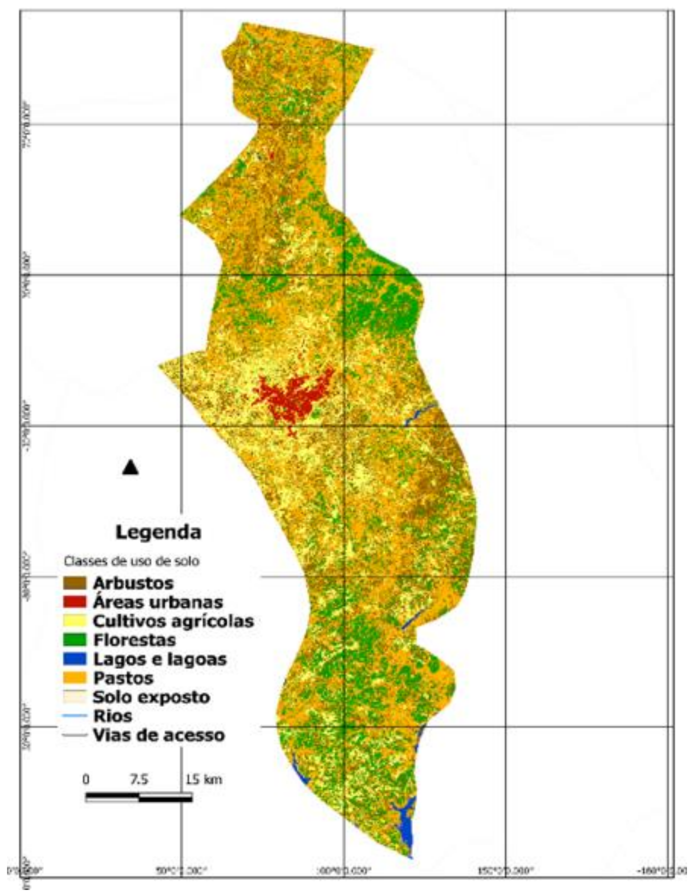
However, as it constitutes a crucial type of information with regard to the geographic environment of natural resources, information from the point of view of land use and occupation in the study area allowed obtaining information on the different classes of land use and occupation, with their respective surfaces.

3.1.2 Classes of use and occupation of land in the municipality of Huambo

The data (referring to the year 2016) obtained from the European Space Agency (ESA) Server, after processing, allowed the analysis of land use and occupation classes, showed that the study area is covered by different classes themes with their respective areas.

This analysis showed that the municipality of Huambo has 9 (nine) distinct classes (figure 4).

Figure 4- Map of land use and occupation classes in the municipality of Huambo – 2016



The analysis allowed us to estimate that about 73% of the municipality of Huambo is covered by vegetation classes (agricultural areas - 32%, forest areas - 20%, pastures/herbaceous vegetation - 13% and shrubs - 8%) and the rest (27 %) share the other classes of land use (urban area, bodies of water and exposed soil). It should be noted that, in the map in Figure 5, many of the areas covered by herbaceous vegetation may in some cases correspond to inhabited rural areas, since as is common, rural areas occur in areas close to areas of low vegetation.

Cabral et al. (2010), the spatial distribution of land cover is also related to the behavior of water flow, depending on local geological conditions. In this sense, the existence of a lot of herbaceous vegetation in the study area may be related to the existing springs, bodies, and watercourses.

The importance of this type of information occurs at various levels (scientific, resource management and policy definition) and covers various human activities, also resulting in the fact that land use is a determining factor in land use and consequently in its value. (Sanfilipo, 2014). The production of information on land occupation/use has become increasingly relevant, as the demands and needs in terms of environmental management and planning grow.

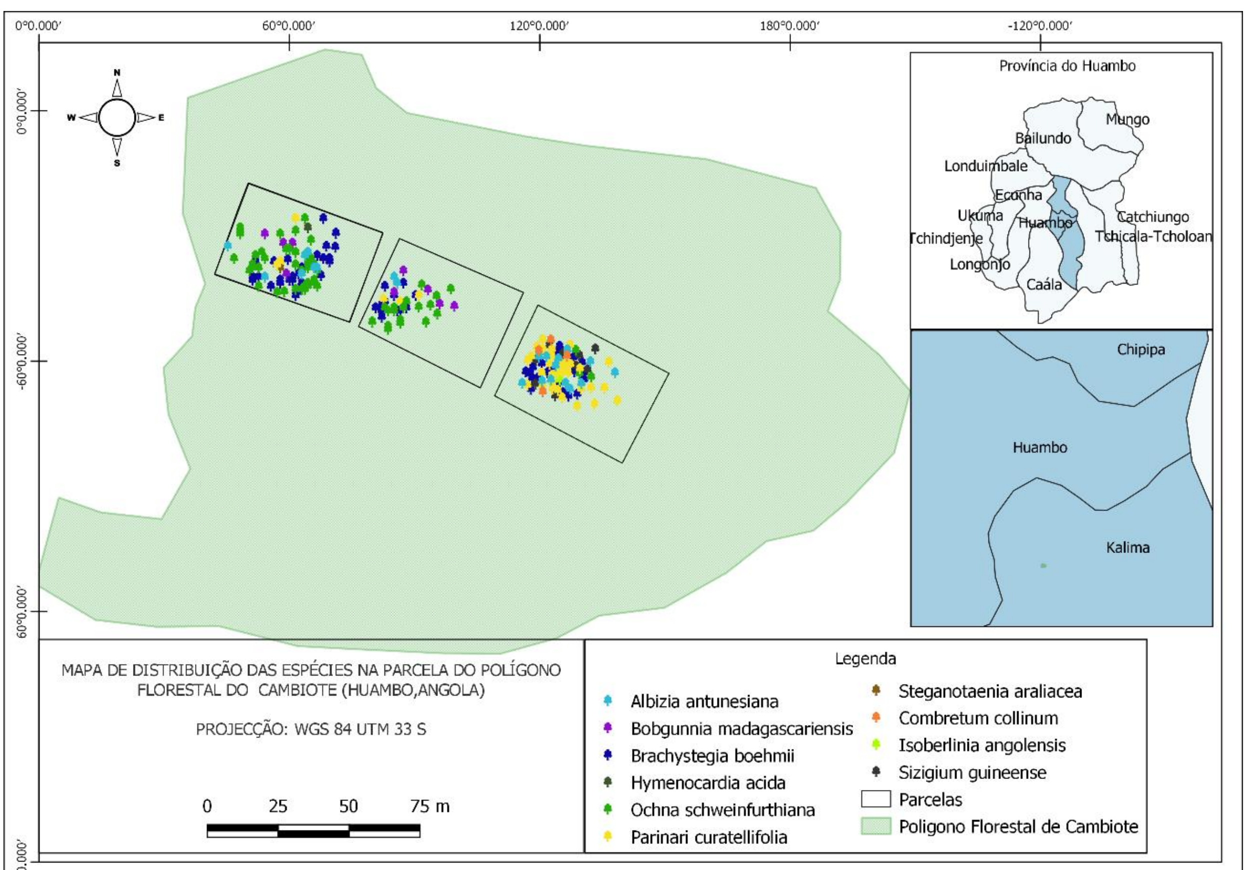
Because the previous analysis (figure 4) only refers to the year 2016, it is recommended in future studies that an analysis be carried out with a larger temporal scale, to understand the dynamics of the vegetation in the municipality of Huambo.

3.1.3 Spatial distribution of species in the plots under study

The map represented in figure 6 clearly shows how the species are distributed in the parcleas under study; as the legend of the same reflects, the difference in distribution is notable for the differentiated coloration of the species. In other words, the greater or lesser occurrence of each species in the plots can be seen by the color of the species.

The map clearly shows the sparse or random distribution of individuals and species. On the other hand, in the first two plots (from left to right) the highest occurrence of Ochna schweinfurthiana, followed by Brachystegia boemii and in the last plot, Parinari curatellifolia can be observed (figure 5).

Figure 5- Species distribution map in the Cambiote forest polygon plot (Huambo)



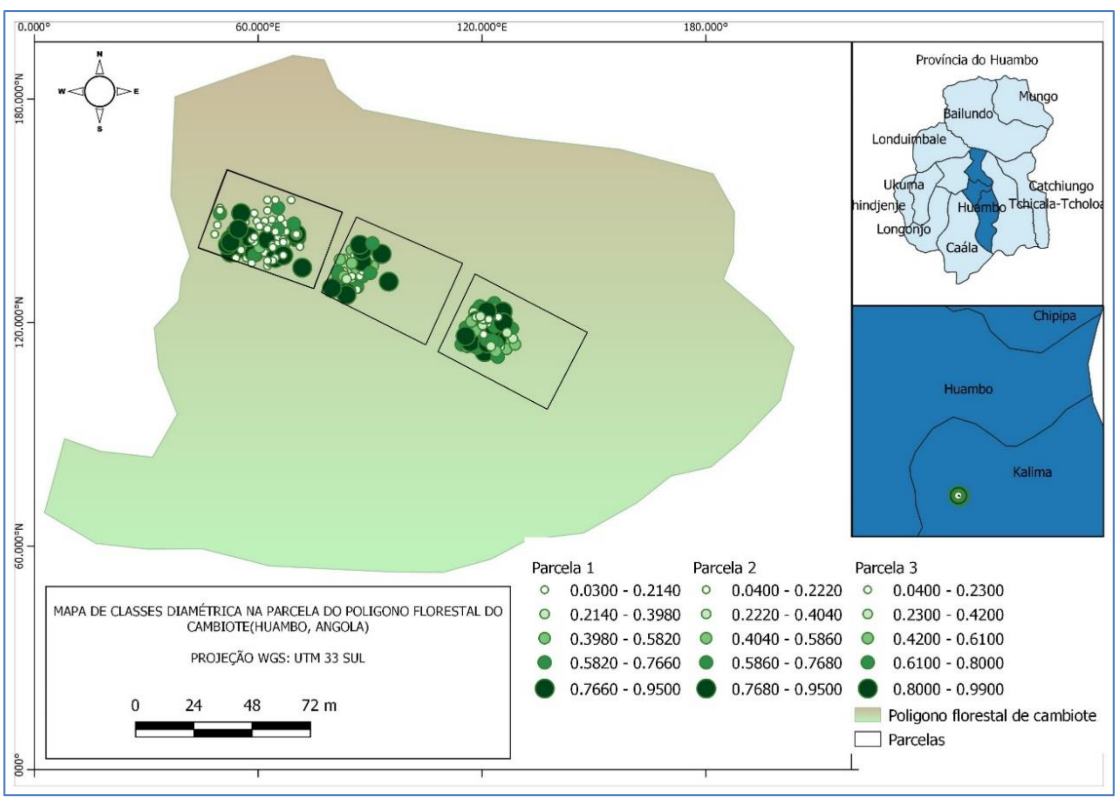
Source: Authors (2022)

The random distribution mentioned above is explained by the fact that a natural forest is studied, where seed dispersal factors and, therefore, individuals are intrinsically linked to natural factors. This idea corroborates Negrini et al. (2012), who state that the dispersion of propagules in natural forests, in addition to other factors, can influence the spatial distribution of individuals of a given tree species, which tends to be random, although sometimes they occur as aggregate or uniform in spatial ecology.

Nascimento et al. (2001), showed in their study that the vegetation, in the sample of interest, presented a higher proportion of species with random distribution and some aggregated or with a tendency to aggregation. The author explains that the changes in the forests were due to commercial exploitation. Do Nascimento et al. (2002), considers that the knowledge of the spatial distribution of each species in the forest is of fundamental importance as a basis for ecosystem management. De Araújo et al. (2014) claims to have found in their study completely random spatial patterns for species native to tropical ecosystems of the Brazilian cerrado (*Tapirira guianensis*, *Acrocomia aculeata* and *Luehea divaricata*).

As for the map of diameter class in the plots of the forest polygon of Cambiote (Huambo), represented by figure 7, it gives the greatest perception of how the diameter classes are represented within each plot. Thus, in the same map, the green color shows individuals with greater diameter and as the green color decreases, the diameter of the classes decreases. See figure 6.

Figure 6- Diametric class map in the Cambiote forest polygon plot (Huambo)



Source: Authors (2022)

It is possible to notice on the map the existence of clusters of groups of individuals with a larger diameter and, at least in the first plot (on the left), a group with a smaller one.

Studies with spatial distribution of aggregate-type diameter classes were reported by different authors as described. In the first case, Bernasol and Lima-Ribeiro (2010) showed in a study that the diametric structure was verified by the frequency distribution of six size classes. The species presented aggregated spatial distribution, with the smallest individuals spatially disjoint from the largest, except for one (*Qualea grandiflora*), and diametric distribution in the form of "inverted J", although with some peculiarities. This suggests differences in the structural pattern of the five populations studied and, consequently, in the structuring and dynamic processes of each species.

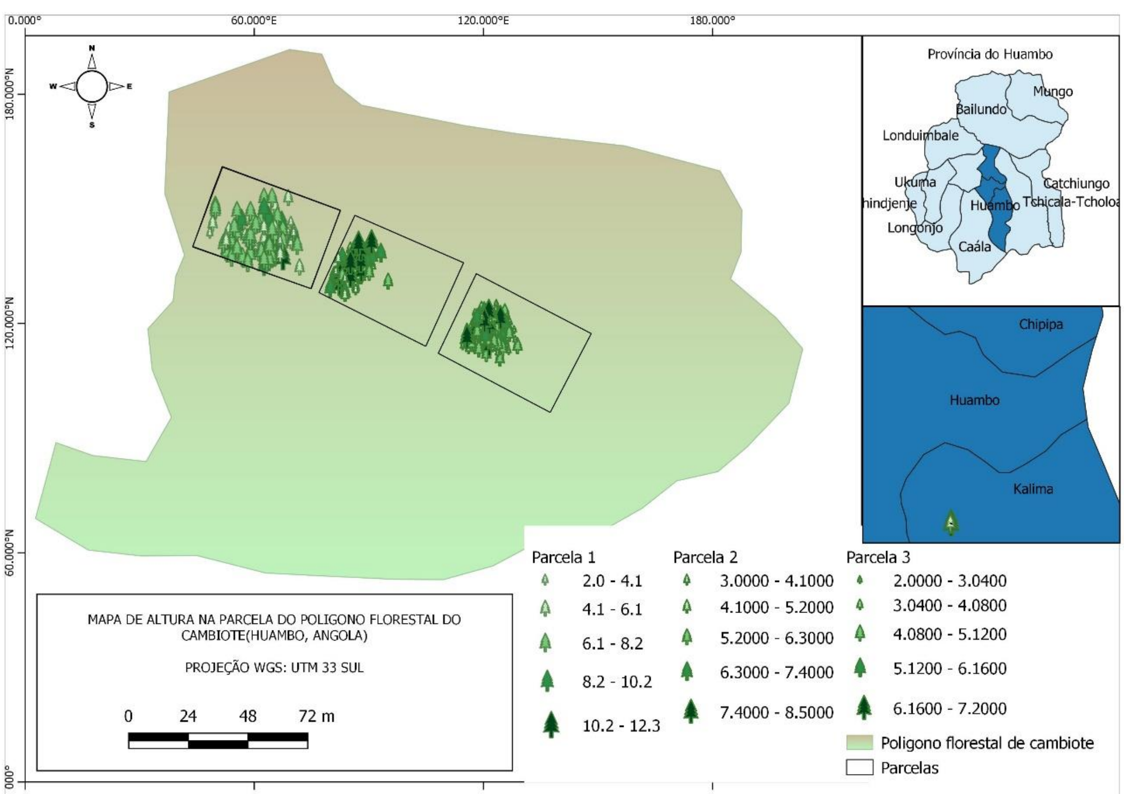
De Pádua-Teixeira and Assis (2007), explain the aggregate distribution in the studied forest by stating that the highest densities in the first diameter classes and the distribution close to the "inverted J" are indicative that the populations studied have a great self-regenerative capacity. The discontinuity in the distribution by classes, observed for M. ovata and E. florida, is due to the presence of a few individuals with an excessively larger size than the other individuals of these populations. De Pádua-Teixeira and Assis (2007) also state that the predominance of the aggregate pattern, observed in their study, corroborates many studies (Nascimento et al., 2001; Nascimento et al., 2002), since this distribution pattern has been highlighted as the most observed in nature and native forests.

The map that distinguishes the distribution of height classes in the plots under study, represented in figure 8, illustrates how the height groups of the species are distributed. As in the previous map, the green color indicates higher height class. In figure 8 the distribution of heights in the three plots is quite heterogeneous for the highest classes of heights and homogeneous for the middle classes.

Plots 2 and 3 (from left to right) show a certain aggregation pattern for the highest height classes, although what predominates in the three plots are the average heights for the values presented. The same map, of the study area designated in green color, where the plots represented show the heights of the species in terms of their color in the map legend and the lighter tones are species with less height and the darker tones are species with greater height of the area where the study was carried out.

These results in figures 6, 7 and 8 show the state of development of the forest studied, which was also observed in loco.

Figure 7- Height map in the Cambiote forest polygon (Huambo)



Source: Authors (2022)

Almeida and Cortines (2012), in the analysis of the population structure, observed that the population had the largest number of individuals concentrated in the classes of lower height and diameter, with the number of individuals in the first class of diameter and height being significantly higher than the number of individuals from other classes. These data indicate that the population is growing; this last statement explains the difference between the results of these authors and those found in the present study.

A consideration to be considered in the present study and in the studies of the researchers mentioned above results from the study by De Araújo et al. (2014), who indicate that individuals from the lower height and diameter classes are those who guarantee the maintenance of the population, although they suffer higher mortality rates, while individuals from the larger size classes are those that are reproductively mature and potentially responsible for production of seeds.

3.2 Dendrometric data of the Miombo forest of Cambiote (Huambo municipality)

Table 2 shows the dendrometric data of the plots under study in the Miombo forest.

Table 2 - Forest dendrometric data

<table>
<tr><th colspan="8">Plot 1</th></tr>
<tr><th>Species</th><th>g</th><th>v</th><th>g/ha</th><th>v/ha</th><th>g/ha</th><th>v/ha</th><th>N/ha</th></tr>
<tr><td>Acid hymenocardia</td><td>0.003</td><td>0.006</td><td>0.06</td><td>0.13</td><td rowspan="7">1,088</td><td rowspan="7">2,882</td><td rowspan="7">140</td></tr>
<tr><td>Bobgunnia madagascariensis</td><td>0.006</td><td>0.014</td><td>0.12</td><td>0.28</td></tr>
<tr><td>Brachystegia boehmii</td><td>0.007</td><td>0.016</td><td>0.13</td><td>0.32</td></tr>
<tr><td>Rothmannia Engleriana</td><td>0.008</td><td>0.026</td><td>0.17</td><td>0.52</td></tr>
<tr><td>Schweinfurthian ocha</td><td>0.009</td><td>0.024</td><td>0.18</td><td>0.48</td></tr>
<tr><td>Erythrina abyssinica</td><td>0.009</td><td>0.027</td><td>0.18</td><td>0.54</td></tr>
<tr><td>Anthunesian albizia</td><td>0.012</td><td>0.031</td><td>0.24</td><td>0.62</td></tr>
<tr><th colspan="8">Plot 2</th></tr>
<tr><th>Species</th><th>g</th><th>v</th><th>g/ha</th><th>v/ha</th><th>g/ha</th><th>v/ha</th><th>N/ha</th></tr>
<tr><td>Pseudolachnostylis maprouneifolia</td><td>0.002</td><td>0.003</td><td>0.032</td><td>0.062</td><td rowspan="7">0.524</td><td rowspan="7">1.177</td><td rowspan="7">140</td></tr>
<tr><td>Terminalia brachystemma</td><td>0.002</td><td>0.004</td><td>0.048</td><td>0.083</td></tr>
<tr><td>Pericopsis angolensis</td><td>0.004</td><td>0.006</td><td>0.073</td><td>0.113</td></tr>
<tr><td>Bobgunnia madagascariensis</td><td>0.004</td><td>0.012</td><td>0.085</td><td>0.238</td></tr>
<tr><td>Anthunesian albizia</td><td>0.004</td><td>0.009</td><td>0.075</td><td>0.175</td></tr>
<tr><td>Ochna schweinfurthiana</td><td>0.005</td><td>0.012</td><td>0.102</td><td>0.233</td></tr>
<tr><td>Brachystegia boehmii</td><td>0.006</td><td>0.014</td><td>0.111</td><td>0.273</td></tr>
<tr><th colspan="8">Plot 3</th></tr>
<tr><th>Species</th><th>g</th><th>v</th><th>g/ha</th><th>v/ha</th><th>g/ha</th><th>v/ha</th><th>N/ha</th></tr>
<tr><td>Combretum collinum</td><td>0.001</td><td>0.001</td><td>0.011</td><td>0.012</td><td></td><td></td><td></td></tr>
</table>

Ochna schweinfurthiana	0.002	0.002	0.037	0.036	0.527	1,001	140
Guinean Syzygium	0.003	0.004	0.063	0.070			
Parinari curatellifolia	0.004	0.007	0.077	0.135			
Isoberlinia angolensis	0.005	0.013	0.096	0.268			
Brachystegia boehmii	0.005	0.009	0.102	0.180			
Albizia anthunesiana	0.007	0.015	0.142	0.299			

Source: Authors (2022)

Plots 2 and 3 showed similar values in basal area per hectare, volume per hectare and number of individuals per hectare; there were only significant differences in the first two variables in relation to the first plot. The individuals of the species in the first plot have a diameter (DBH) and height (h) greater than those of plots 2 and 3, variables that are fundamental and frequent measurements to be obtained from the trees and constituting the basis of calculation for the estimation of the basal area per hectare and volume and hectare, in addition to other factors such as constant fires, human anthropic actions and climate change in the study area, negatively affected the species present in this region, reasons that some individuals had small daps and heights.

3.2.1 Number of individuals per species

In the first Plot, it was observed that the population consisted of 87 individuals, and regarding the number of individuals per species, we highlight: *Ochna schweinfurthiana* with 40, *Brachystegia boehmii* 31, *Albizia anthunesiana* 7, *Bobgunnia madagascariensis* 4, *Erythrina abyssinica* 3, *Rothmannia engleriana* 1, *Hymenocardia acid* 1.

As we can see, the species *Ochna schweinfurthiana* was dominant with 40 individuals. This factor is due to being a good honey species, many species of edible larvae feed on its leaves and vulnerable to fire, makes explorers resolve it for beekeeping; However, the species, *Rothmannia engleriana* and *Hymenocardia acida* with 1 individual each, were the least representative and are more used for handicrafts and for firewood and charcoal production.

According to Sanfilipo (2014), some species that, due to their characteristic of exploitation, serve as a source of energy tend to be more sacrificed to the detriment of those that are economically more useful keeping them alive.

In the second Plot, the population consisted of 44 individuals, namely: *Ochna schweinfurthiana* 19, *Brachystegia boehmii* 15, *Bobgunnia madagascariensis* 5 *Albizia anthunesiana* 2, *Pericopsis angolensis* 1, *Terminalia brachystemma* 1 and *Pseudolachnostylis maprouneifolia* 1. The representative species of this plot was *Ochna schweinfurthiana* with a total of 19 individuals making it dominant, the less representative species were *Pericopsis angolensis*, *Terminalia brachystemma* and *Pseudolachnostylis maprouneifolia* with only 1 individual per species.

The number of individuals per species in the third plot was 81 individuals, which are: *Parinari curatellifolia* 31, *Brachystegia boehmii* 20, *Albizia anthunesiana* 13, *Syzygium guineense* 9, *Combretum collinum* 4, *Ochna schweinfurthiana* 3, *Isoberlinia angolensis* 1.'The species of *Parinari curatellifolia* having the highest number of individuals and being dominant with 31 individuals and due to the fact that they are preserved by the peasants for the use of the fruits, and little representative in this plot was the species *Isoberlinia angolensis* with only 1 individual represented.

CETAC (2019) carried out a study on the forest ecosystem of Calima, where the following species are the most numerous: *Anisophyllea boehmii* and *Brachystegia spiciformis*, with 140 and 130 individuals per hectare, respectively. The species *Eugenia angolensis* and *Pericopsis angolensis* were the least abundant, with one individual each.

3.2.2 DBH and average height

The results obtained on the average height classes of the plots are described in table 3.

Table 3 - Average Height Class of the plots

Species / Installments	DAP 0-0.10 (m)			+ 0.10 (m)		
	P1	P2	P3	P1	P2	P3
Hymenocardia acid	0.064					
Bobgunnia madagascariensis	0.088	0.07				
Brachystegia boehmii	0.09	0.08	0.081			
Erythrina abyssinica				0.11		
Ochna schweinfurthiana		0.08	0.05	0.11		
Albizia anthunesiana		0.069	0.10	0.12		
Rothmannia engleriana				0.10		
Pseudolachnostylis maprouneifolia		0.045				
Terminalia brachystemma		0.055				
Pericopsis angolensis		0.068				
Guinean Syzygium			0.06			
Isoberlinia angolensis			0.078			
Combretum collinum			0.03			
Parinari curatellifolia			0.07			

Source: Authors (2022)

As for the highest (average) height, the species *Rothmannia engleriana* was dominant in this aspect with 8 m, knowing that this species can reach up to 8 m in its natural habitat and the edaphoclimatic conditions that help its development. Unlike this result, Cachenhe et al. (2018), mentions the species *Brachystegia spiciformis* as the one with the highest height with 9.3 m, having stood out in the entire universe of the miombo area in which the study was carried out.

These differences can be explained by the differences in ecological conditions offered by each of the study areas.

3.2.3 Shell thickness and crown diameter

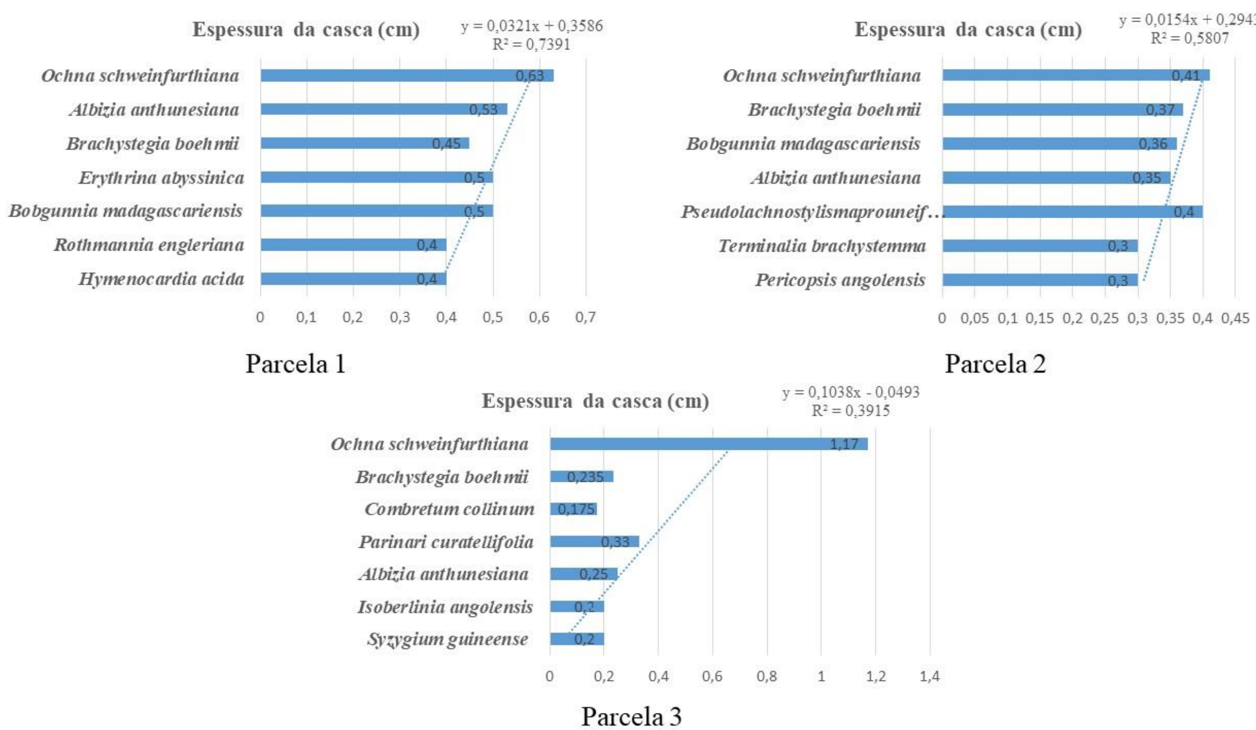
Firstly, it is important to mention that the species and individuals of the 3 plots are approximately the same age 30 years old (from the date the forest was left intact according to the owner), and can be included in the group of equine-type forests (only taking into account the counts the age, without the observation of platation or being exotic).

As for the thickness of the bark, the species *Ochna schweinfurthiana* was 1.17 cm thick, dominating all species present in the universe of the 3 plots in which the study was carried out; in turn, the species *Combretum collinum* and *Brachystegia boehmii* had a lower value for this variable. However, there is also a similarity between the size of the shell thickness of the species in plots 1 and 2. See figure 8.

As in the previous variable, considering that the forest has been intact for 30 years (depending on the owner), these differences are explained by the differences in ecological conditions (particularly soil conditions) offered by each plot.

On the other hand, this difference may be related to the canopy tangency, that is, some individuals may be competing for the reach of sunlight, which favors the dominant individuals over the dominated ones, as described below in the data from the cup diameter.

Figure 9- Bark thickness of the 3 plots



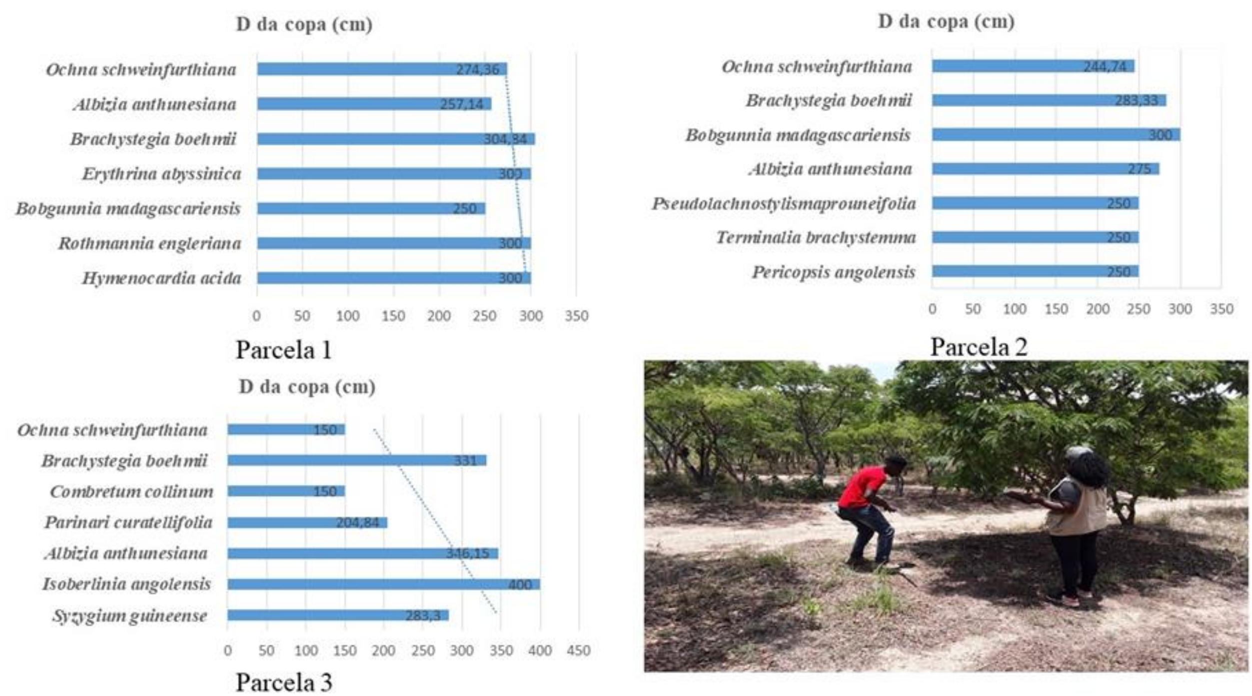
Source: Authors (2022)

In the study by Cachenhe et al. (2018), the biggest highlight for the variable under analysis was *Brachystegia boehmii* with 0.566 cm. Regarding the crown diameter, it was observed that in the inventoried area, the species *Isoberlinia angolensis*, which occurs only in plot 3, stood out with 400 cm, followed by the species *Albizia anthunesiana* (346 cm), *Brachystegia boehmii* (304 cm) and *Hymenocardia acida*, *Bobgunnia madagascariensis*, *Erythrina abyssinica* and *Rothmannia engleriana* with 300 cm each.

As for the species with the smallest canopy diameter, they were found in plot 3, which is related to the previous variable, one can see the existence of a limiting factor for the development of species in this plot. This can be seen with *Ochna schweinfurthiana*, which in plot 3 has a very low average value and in plot 1 a high average value.

The figure below presents in detail the information of the diameter of the canopy of the 3 parcels.

Figure 10- Diameter of the canopy of the 3 parcels



Source: Authors (2022)

Cachenhe et al. (2018) in their study carried out in the Miombo forest in Chianga stated that the *Brachystegia boehmii* species had a larger crown diameter value (544.7 cm) and the *Sterculia quinquebola* species with 13.3 cm that stood out with lower cup diameter. The study of the bark thickness of forest species is important to understand the ecology of the species themselves.

For Kempe et al. (2018) the trunks of *Adansonia* (a Miombo species, which occurs in Angola as well) have a thick, fire-resistant bark and forest fires occur regularly in their habitat (savannah), we examined with the African *Adanonia digitata* and the Australian *Adansonia gregorii* if the fruit offers protection from the high heat typically experienced in wildfires.

Tsobeng et al. (2020) consider that the bark thickness of a tree species is related to the phenotypic variation and domestication of a species. Quantification of the tree canopy area and aboveground biomass is essential for monitoring ecosystems' ecological functionalities, e.g., carbon sequestration and habitat provision. In this way, Mareya et al. (2018) have recommended using the high spatiospectral resolution remote sensing data to study tree canopy in Miombo woodlands that are vastly existent in Southern Africa developing countries. Kuyah et al. (2016) recommend the use of canopy cover data for carbon sequestration studies in Miombo forests.

4. Conclusion

The geoprocessing techniques applied to forest management through the realization of a traditional forest inventory with the aid of GIS tools in the Miombo forest polygon in Cambiote (Huambo) made it possible to locate the plots, understand the spatial distribution of individuals according to species, diameter and height, as well as floristic composition.

The analysis of forest inventory data from a dendrometric and spatial perspective allowed us to study a population of 212 individuals, in which the species *Ochna schweinfurthiana* with 54 individuals, *Brachystegia boehmii* 66 and *Parinari curatellifolia* 31 stand out. The average basal area per hectare was 0. 7, the average volume per hectare was 1.7 and the average number of individuals per hectare was 140. The analysis in the spatial perspective showed greater spatial distribution, in the study area, of these species.

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