Artigo

WATER RESOURCES AND PALM OIL CROPS IN THE TOMÉ-AÇU MICRO REGION SUB-WATERSHEDS, AMAZON, BRAZIL[1]

RECURSOS HÍDRICOS E DENDEICULTURA NAS SUB-BACIAS DA MICRORREGIÃO DE TOMÉ-AÇU, ESTADO DO PARÁ

RECURSOS HÍDRICOS Y EL CULTIVO DE DENDE EN LAS SUBCUENCAS DE LA MICROREGIÓN DE TOMÉ-AÇU, ESTADO DE PARÁ

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ABSTRACT: When analyzing the territorial dynamics of palm oil crops, is faced with the lack of discussion about the use of water in palm oil production. Discussions about the use and excess of this input are incipient in studies on palm oil cultivation, and it is important to emphasize topics such as: raw materials, energy, stable climate and favorable water balance. However, as important as the edaphoclimatic factors, are the studies on the watersheds and the watercourses where palm oil crops (Elaeis guineenses) are located. In this context, the physical aspects (linear and sandy) of the Tomé-açu Micro region watersheds (MRGTA) were analyzed. The purpose of the research was to draw an overview of the palm oil territory on water resources and their social and environmental implications. Thus, a fieldwork was carried out to collect data and systematize a georeferenced database with information plans through the Geographic Information System (GIS). As a result, five River Sub Watersheds (SBH) were identified, with variable areas and huge hydrological potential, reaching 13,846.12km² of drainage area, the Acará River SBH. The data showed 22,870.94km² of continuous palm oil monoculture patches, which has been expanding since the 1980s over MRGTA SBHs. Thus, the expansion of palm oil stands may be contributing to the degradation of the environment, especially of water resources, generating conflicts of interest that must be managed based on technique and legislation in order to reduce changes in ecosystems of the region.
Keywords: Agribusiness; Morphometry; Palm oil; Water.

RESUMO: Ao se analisar as dinâmicas territoriais da dendeicultura, depara-se com a ausência da discussão sobre o uso da água na produção do dendê. As discussões sobre o uso e abusos desse insumo são incipientes nas literaturas sobre cultivo da palma de óleo, sendo prioridade temas como: matérias-primas, energia, clima estável e o balanço hídrico favorável. Entretanto, tão importante quanto às características edafoclimáticas, são os estudos sobre bacias hidrográficas e corpos hídricos sobre os quais estão assentados os cultivos do dendê (Elaeis guineenses). Neste contexto, fez-se análises das características físicas (aspectos lineares e areais) das sub-bacias hidrográficas da Microrregião de Tomé-açu (MRGTA), tendo como objetivo traçar um panorama do território do dendê sobre os recursos hídricos e compreender suas implicações socioambientais. Para tanto, realizou-se um trabalho de campo para coletar dados e, posteriormente, construir uma base de dados georreferenciados, com planos de informações através do Sistema de Informações Geográficas (SIG). Como resultado, foram identificadas cinco Sub-Bacias Hidrográficas (SBH), com áreas variáveis e enorme potencial hidrológico, destacando-se com 13.846,12 km² de área de drenagem, a SBH do rio Acará. Através dos dados, foram distinguidos 22.870,94 km² de contínuas manchas de monocultura de Elaeis guineenses, que vêm se expandindo desde da década de 80 sobre as SBH da MRGTA. Desta forma, o cenário de expansão dos talhões de dendê pode estar contribuindo para a degradação do ambiente, em especial, dos recursos hídricos, gerando conflitos de interesse que devem ser administrados com base na técnica e na legislação, no intuito de reduzir as alterações nos ecossistemas da região.
Palavras-Chave: Agronegócio; Morfometria; Óleo de palma; Água.

RESUMEN: Al analizar las dinámicas territoriales de la palma aceitera, se encuentra la falta de discusión sobre el uso del agua en la producción de palma aceitera. Las discusiones sobre el uso y abuso de este insumo son incipientes en la literatura sobre el cultivo de la palma aceitera, dando prioridad a temas como: materias primas, energía, clima estable y balance hídrico favorable. Sin embargo, tan importante como las características edafoclimáticas, son los estudios sobre cuencas hidrográficas y cuerpos de agua sobre los que se asientan las plantaciones de palma aceitera (Elaeis guineenses). En este contexto, fueron realizados análisis de las características físicas (aspectos lineales y arenosos) de las cuencas hidrográficas de la Microrregión de Tomé-açu (MRGTA), con el objetivo de trazar un panorama del territorio palmero sobre los recursos hídricos y comprender su implicaciones socioambientales. Por ello, se realizó un trabajo de campo para la recolección de datos y, posteriormente, la construcción de una base de datos georreferenciada, con planos de información a través del Sistema de Información Geográfica (SIG). Como resultado se identificaron cinco subcuencas hidrográficas (SBH), con áreas variables y enorme potencial hidrológico, destacándose con 13.846,12 km² de área de drenaje, la SBH del río Acará. A través de los datos se distinguieron 22.870,94 km² de parches continuos de monocultivo de Elaeis guineano, que se vienen expandiendo desde la década de los 80 en el SBH de la MRGTA. De esta forma, el escenario de expansión de los rodales de palma aceitera puede estar contribuyendo a la degradación del medio ambiente, en particular, de los recursos hídricos, generando conflictos de interés que deben ser manejados con base en la técnica y la legislación, con el fin de reducir los cambios en los ecosistemas. en la región.
Palabras-Clave: Agroindustria; Morfometría; Palma aceitera; Agua.

INTRODUCTION

The earth is called the “planet water” because two thirds of its earth surface is covered by this substance as seas, oceans, rivers, lakes; below it in the form of groundwater and soil moisture; in the atmosphere, and also in the water vapor (Whately and Campanili, 2016).

Through the hydrological cycle, water is a clean, safe and renewable resource that is not always well distributed in space and time. Therefore, it is important that its use be managed efficiently, so that everyone can access this resource, which is essential to the existence of life on Earth (Villela and Mattos, 1975; De Carli, 2015). However, in the growing panorama of economic development, it is important to elaborate studies on the uses and uncontrolled use of water, since, although renewable, it is a finite fluid (Villela and Mattos, 1975).

With the accelerated process of growth and development of society, we have watched an intense degradation of the environment, especially of the planet's water (Carvalho et *al.*, 2012). Alves et *al.* (2018) highlight the problem of local overexploitation of natural resources such as water, mainly due to socioeconomic conditions that do not respect the limitations of the natural environment.

In 2014, Brazil already witnessed water scarcity events that made clear the limitations and difficulties of ensuring the availability of this resource in quantity and quality, as rainfall levels were much lower than expected, affecting urban supply and rural activities, among others (Lopes, 2015). In the rural context, water is widely used, in general, in animal husbandry and in the process of irrigation of crops, leaving it a natural element to be considered an input of the productive process, with economic value (Araújo, 2000). Still, according to the author, this natural input, indispensable to life, has been treated as an abundant resource freely available, being a cause for concern.

The use of surface or groundwater in irrigation, aiming to supply the rainfall deficiencies in agribusiness production, has been analyzed in several ways in Brazil, mainly in relation to irrigation techniques and water conflicts in the context of agribusiness capitalist relations (Kaltner *et al*., 2004; Furlan Júnior *et al*., 2006; Thomaz Junior , 2010) , because water is critical to plant metabolism, and reducing its availability can affect crop growth, development and productivity (Ferreira, *et al*., 2016).

In the northeast of the State of Pará, in the palm oil agribusiness chain, the water input is essential to the cultivation of the bunch and the production of palm oil derivatives (*Elaeis guineenses*) (Müller *et al*., 1997; Müller *et al*., 2006). Thus, the palm oil agribusiness in MRGTA lacks the water system, sources, and groundwater, as they are indispensable for the cultivation, processing of fresh harvested fruit, to transform them, for example, into oil (Alves et al., 2013).

According to Müller *et al*. (2006), to produce one ton of palm oil, an average of 6.2 thous./m^3 of water is used. Therefore, we are facing an agroindustry, supported by the discourse of employment, income and social inclusion, which monopolizes the use of land, labor and water resources. This leads us to work with the hypothesis that, due to the large availability of water in the MRGTA, it is important to carry out studies of the physical characteristics of the MRGTA River Basins (SBH), where the mosaics of palm oil crops are inserted.

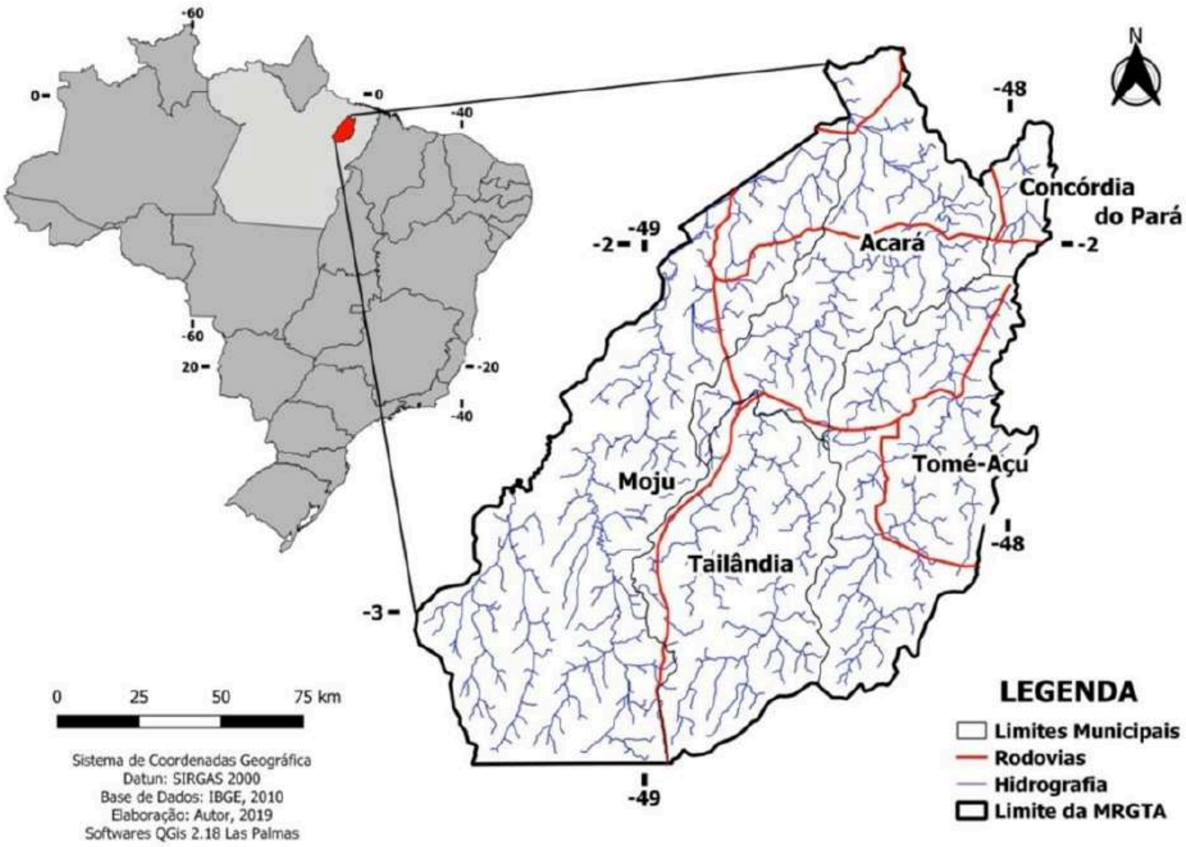
In this paper, we see the palm oil production as agribusiness, considering the empirical situation, the palm oil and the integrated analysis of the water resources of this micro region of northeastern Pará. Thus, this is an overview of the morphometry of the MRGTA SBH, formed from the physiographic data and how they contribute to palm oil production, since the use of this natural resource is substantial to maintain the nurseries, as well as the enterprise in general.

MATERIALS AND METHODS

Study Area

In this research will be considered as study area the Tomé-açu Micro region (MRGTA), which is located in the greater Northeast region of the State of Pará, composed by the municipalities of: Acará, Concórdia do Pará, Moju, Tailândia and Tomé-açu, as shown in Figure 1. MRGTA has a total area of 23,704,079 km² and in 2016, according to the 2010 Demographic Census of the Brazilian Institute of Geography and Statistics (IBGE), has a population of 325,988 inhabitants.

Figure 1 - Location of Tomé-açu Micro Region (MRGTA).



Fonte: Organized by the authors.

The history of MRGTA has been highlighted since the beginning of the 21st century, especially in rural areas, which has been the focus of attention and integration strategies of the Amazon with the rest of Brazil, through the diversification and expansion of the industrial sector, especially the palm oil production industry.

The extensive palm oil monoculture is run by large agribusiness companies such as: AGROPALMA, BBB/GALP, BIOPALMA and MARBORGES; in the rural area of Concórdia do Pará is commanded by BIOPALMA and DENDÊ TAUÁ; in the rural area of Moju by BBB/GALP, AGROPALMA, BIOPALMA, MARBORGES, GUANFENG DO BRASIL and WM AGROINDÚSTRIA LTDA; in the rural area of Tailândia by BBB/GALP, AGROPALMA and BIOPALMA and in the rural area of Tomé-açu by BBB/GALP and BIOPALMA (Nahum and Malcher, 2012).

Methodological Procedures

For the execution of the research, the steps were followed:

Step 1 - Development of a Georeferenced Database (BDG): Secondary databases of Federal Government institutions were used, such as: Limits of the municipalities of the Brazilian Institute of Geography and Statistics (IBGE), watershed limits, drainage network, water body of the National Water Agency (ANA). In the elaboration of the BDG and the basemap, the maps were converted, digitized and elaborated, using the Geographic Information System (GIS) QGis program. 2.18.

Step 2 - Preparation of the Digital Terrain Model (MDE): A mosaic of scenes with articulation compatible with the 1: 250.000 scale (IBGE) was created through the frames:SA-22-Z-A, SA-22-Z-B, SA-22-Z-C, SA-22-Z-D, SA-22-X-D, SA-23-Y-A e SA-23-V-C, from images of Brazil in Relief, from data by Shuttle Radar Topography Mission (SRTM) with a spatial resolution of 60 meters, freely available from Embrapa Satellite Monitoring. (Miranda, 2005). With the SRTM data, and from the “Terrain Analysis Using Digital Elevation Models (TauDEM)” toolkit on the QGis 2.18 platform, it was possible to generate a Digital Elevation Model (MDE) as well as contour lines, watershed delimitation, drainage network, among other physiographic characteristics of the sub-watersheds (Pan, et *al*., 2012).

The drainage area of the MRGTA watershed was subdivided into five smaller Sub-watersheds (SBH) for detailing the water bodies, named: SBH-1, SBH-2, SBH-3, SBH-4 and SBH -5, considering the main rivers of MGTA.

Step 3 - Creating the Palm Oil Territory: For mapping the palm oil production areas, the Operational Land Imager (OLI) sensor images were used as an interpretation source aboard the Landsat-8 satellite, with False-Color colored compositions. / 5r-4g-3b, in orbits 223, points 61 and 62 and in orbits 224, points 61 and 62 of 2018, all with spatial resolution of 30 meters. The selected images were obtained free of charge from the U.S. Geological Survey (USGS) public data repository known as EarthExplorer. The visual interpretation and spectral performance of palm oil crops were performed on the Landsat images, based on the elements of: geographical location, size, pattern, shape, texture, color, shade, shadow and ground surface reflectance values. Finally, a supervised classification of Landsat-8 (2018) was performed for mask extraction with the delimitation of palm oil cultivation areas in MRGTA, with Envi 4.8 software (Florenzano, 2008).

Step 4 - Morphometry of the sub-watersheds of the Tomé-açu Micro region: The study of the physiographic characteristics (morphometry) was divided through data extracted from maps, photographs and satellite images. Morphometry was divided into two categories, as required by Villela and Mattos (1975), Pinto *et al*. (1976), Tucci (1993) and Maidment (1993). The first of which are: the linear characteristics (channel hierarchy identification, fork ratio, connection between the average length of the channels, among others); and the second: sand aspects (shape and determination of drainage density, hydrographic density, maintenance coefficient, relief ratio and slope, among others).

RESULTS AND DISCUSSION

Water Resources in MRGTA Sub-watersheds

Water nourishes the forests and maintains palm oil agribusiness production at MRGTA. MRGTA has five Sub-watersheds (SBH), which are dismembered from the micro region boundary and land areas drained by watercourses. In addition, they are peripherally limited by a water divider, as required by Villela and Mattos (1975) and Attanasio (2004). The first identified subwatershed is the Bujaru River (SBH-1), followed by the Ubá River (SBH-2), the Mamorama River (SBH-3), the Moju River (SBH-4) and, finally, the SBH-5 Acará river.

The Moju municipality, after automatic definition of the water dividers, obtained within its municipal boundary three of the five MRGTA sub-watersheds: The Ubá river (SBH-2), the Mamorama river (SBH-3) and the Moju river (SBH-4). Also, in the context of individualization of the sub-watersheds, the great extension of the Moju River (SBH-4) stands out, which was not restricted to the MRGTA municipal border limits. Other drained areas have extended beyond municipal boundaries, such as SBH-4 and SBH-5 (Moju River and Acará River, respectively). The municipality of Concórdia do Pará is on the smallest MRGTA subwatershed: The Bujaru River, as shown in Figure 2. Therefore, it is noted that the MRGTA sub-watersheds may constitute a water resource unit or may have their water dividers beyond the political-administrative boundaries created by the State of Pará itself.

From the results of the geoprocessing, it was quantified that the areas of the drainage land of the MRGTA SBH have variable values of water body sizes and density, with emphasis on the Acará river SBH-5, which has 13,846.12km² over the municipalities. from Acará, Thailand and Tomé-açu. Thus, it represents the largest natural catchment area of MRGTA's precipitation water. In this subwatershed, the length of the watercourse is 2,169.72 km, which has the largest river hierarchy (5th order), which proves that the region has the highest degree of branching analyzed channels. The Moju River SBH, with 4,743.21 km², is the second largest drainage area subwatershed, followed by the Mamorama River (SBH-3), with an area of 2,132.11 km², by the Ubá River (SBH-2), with 1,261.58km², and the Bujaru River (SBH-1), with 610.59km², as shown in Table 1.

According to Soares et *al*. (2016), the use and disorderly occupation of a subwatershed, as well as the expansion of waterproofing, produce the risk of flooding, especially those located in areas of lower topography, such as palm oil cultivation areas that are flattened. In this context, from the results of compactness coefficient (Kc), it was found that MRGTA SBHs are not subject to major flooding, all being regular drainage, since densities (Dd) are between 0.5 and 1.5 km / km² (Villela and Mattos, 1975).

Still, regarding the Kc values of the sub-watersheds, it was found that the most irregular, and not subject to major flooding, is the Moju River (SBH-4) with 3.20 Kc, followed, respectively, by the sub-watersheds of Ubá River, Acará River, Bujaru River and Mamorama River, with 2.67, 2.31, 2.22 and 1.99 Kc, according to Table 1. Comparing the values of compactness coefficient (Kc) and form factor (Kf), it can be verified once again that the sub-watersheds under analysis are not susceptible to flooding, even in the event of intense precipitation, according to Andrade et *al*. (2013).

The MRGTA's SBH drainage networks consist of main and perennial watercourses, as well as intermittent or ephemeral secondary channels that require a minimum area of 6,000 km²/m and a maximum of 8,000 km²/m for maintenance of each meter, which correspond to the Mamorama and Moju River sub-watersheds, respectively. The sinuosity results show that the channels are curved and close to 2.0. Higher values characterize the channels as tortuous, while the intermediate value indicates transitional, regular, and irregular shapes (Schumm, 1963). Other results of morphometric analysis are shown in Table 1.

For the maintenance of water in the SBH, it is essential to calculate the area required to maintain the distance of 1 meter of river flow channel. Defined by the maintenance coefficient (Cm), in this parameter, we identified that in MRGTA, the minimum vital area for the maintenance of 1 meter of the runoff channel in a subwatershed is 3,244.75 km² on the SBH-4 (Moju River), and the maximum area corresponds to 6,381.52 km² (Schumm, 1963).

Although the Moju River subwatershed has the largest vector distance from the main channel (195.90 km) and the highest elevation (72m), this subwatershed has the lowest declivity of watercourses due to the gradient of channels (Gc), which reaches 0.20. However, the highest value given by the relation between the maximum altitude of the watershed and the length of the main channel (Gc), proposed by Horton (1945), is the value of the Bujaru River SBH (0.84), indicating that this region has the highest slope of the watercourses, therefore, the largest surface runoff. Other results of the morphometric characterization of the MRGTA drainage network are presented in Table 1.

Table 1 - Morphometric characterization of the sub-watersheds of the Tomé-açu micro region.

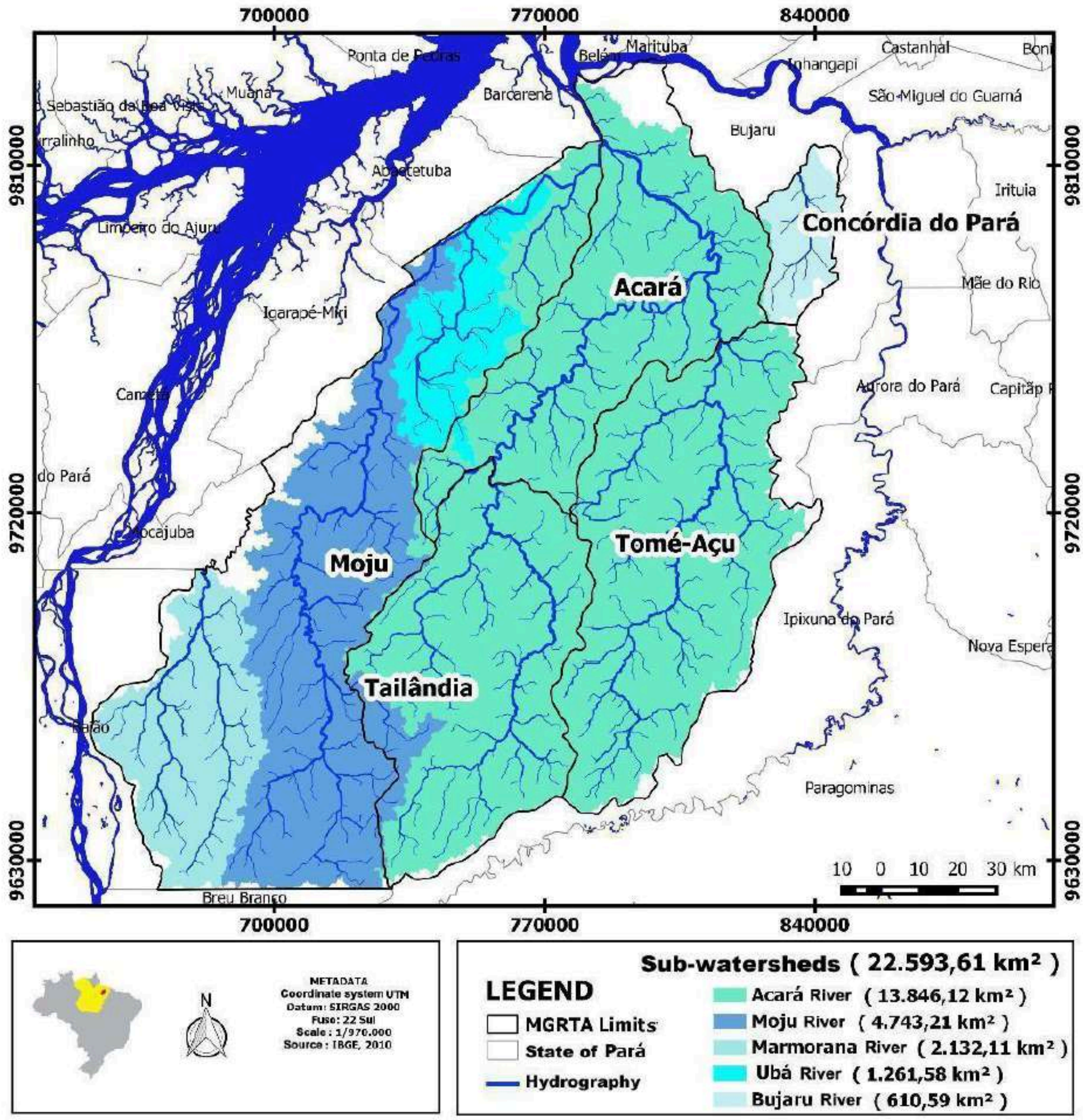
Characteristics	**SBH -1** **Bujaru River**	**SBH -2** **Ubá River**	**SBH -3** **Mamorama River**	**SBH-4** **Moju River**	**SBH -5** **Acará River**
Maximum altitude (Amx)	36	28	70	39	72
Minimum altitude (Ami)	6	18	6	6	6
Altimetric range (Amp) m	30	10	64	33	66
Drainage area (Ad) km²	610,59	1.261,58	2.132,11	4.743,21	13.846,12
Compactness coefficient (Kc) km/km²	2,23	2,69	2,00	3,22	2,33
Maintenance coefficient (Cm) km²/m	3.657,54	3.471,51	3.733,73	3.244,75	6.381,52
Main stream channel length (Lp) km	42,94	74,91	91,39	239,16	354,33
Total length of channels (Lt) km	166,94	363,41	571,04	1.461,81	2.169,72
Drainage density (Dd) Lp/km²	0,27	0,29	0,27	0,31	0,16
Hydrographic density (Dh) Qcb/km²	0,03	0,03	0,03	0,03	0,03
Vector distance from main channel (Dv) km	36,26	73,15	79,14	164,56	195,90
Form factor (Kf) km²/Lp	0,33	0,22	0,26	0,08	0,11
Main channels pattern (Gcp) m/km	0,84	0,37	0,77	0,16	0,20
Circularity index (Ic)	0,20	0,14	0,25	0,10	0,18
Roughness index (Ir) Amp/Dd	109,73	34,72	238,96	107,08	421,18
Main channel sinuosity index (Is) Lp/Dv	1,18	1,02	1,15	1,45	1,81
The stream order in the sub watersheds	3ª	3ª	4ª	4ª	5ª
Perimeter - P (km)	196,82	341,41	330	791,19	979,27
Channel Amounts (Qc)	17	36	64	135	421

Fonte: Organized by the authors.

The hierarchy of rivers (canals), which is the natural organization of a river, occurs in order of smaller volume of water (1st order channels), coming from the hydrological cycle of the waters, heading for the rivers with more flow. In this context, MRGTA's largest water drainage sections have a length of 701.48 km, and 91.11% are represented by the 4th order channels, which do not have interruption in their water flow in any period: droughts or floods. Therefore, its water level is never below the earth's surface.

Figure 2 illustrates that MRGTA SBHs are elongated, a fact that can be verified by the values obtained for the compactness, circularity and form factor indices (Table 1), which indicates low flood susceptibility under regular rainfall conditions.

Figure 2 - Hydrography and sub-watersheds of the Tomé-açu Micro region.



Fonte: Organized by the authors.

Analyzing the percentage of first-order channels, Vitte (2005) states that the greater the number of first-order channels, the greater the fragility of the landscape. Thus, this is the situation of the Rio Acará SBH-5, as it presents 62.7% of the total of first order channels, which is 673 channels. Therefore, even though it is larger in extension area, and therefore larger in rain catchment area, the Moju River sub-watershed, with its 310 first-order channels, can suffer anthropogenic impacts and rainfall erosion, determined by physical (slope, soil types) and economic (land use and occupancy) factors, from different environments to anthropic interference, thus characterizing its environmental fragility (Almeida *et al*., 2016). The SBH-3 and SBH-4 presented an order equal to the 4th order, being classified as small watersheds.

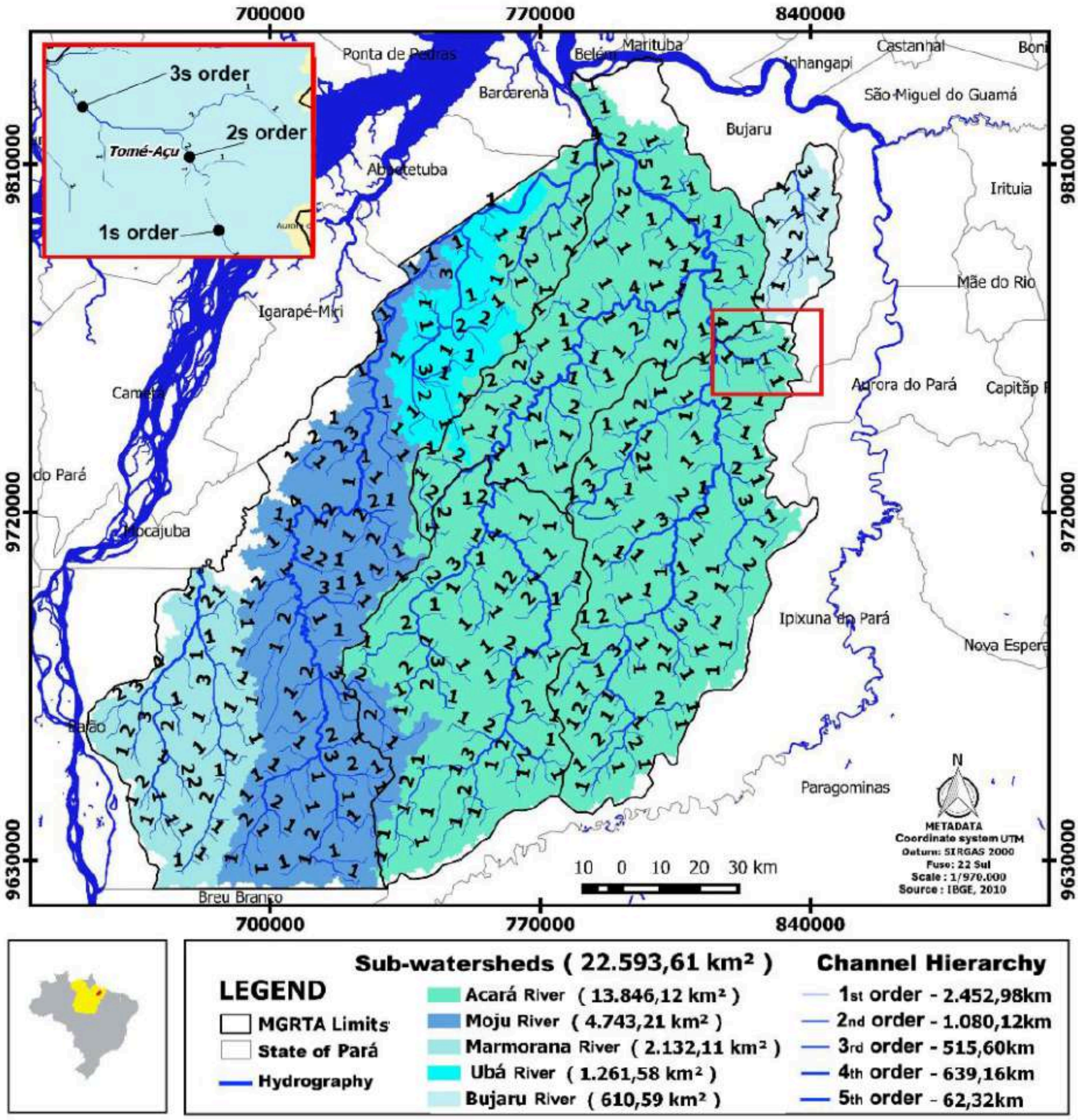
Since the watercourses that make up a sub-basin are classified according to their branching order, we can also represent this feature through the Bifurcation Ratio (Rb) of the MRGTA channels. Rb is the division or separation of watercourses into branches or arms (such as a fork), defined by Horton in 1945.

The bifurcation ratio, according to Villela and Mattos (1975), can range from 2.50 to 9.00. Considering that in MRGTA the average bifurcation of the 1st order channels to the 2nd order channels was 3.58, on average, each 2nd order river receives contribution from three 1st order rivers, which makes them more flow. In this context, we highlight the SBH-1 (Bujaru River) and SBH-3 (Mamorama River) which have the highest Rb values, because their 2nd order channels receive the contribution of four channels of 1st order, representing the largest volume of water in the exutory.

It was identified that the 3rd order channels received from the 2nd order channels, in the analyzed sub-basins, was 5.24, and the 4th order compared to the 3rd order, 4.16. 3rd order receive the average contribution from five 2nd order channels, and the 4th order receive the average contribution from four 3rd order channels. According to Villela and Mattos (1975), the highest bifurcation ratios observed were between the 4th and 5th order channels. In addition, the 1st and 3rd order channels exhibited similar bifurcation behaviors. However, in MRGTA, the result of the Rio Ubá stands out, where a 3rd order channel receives the contribution of nine 2nd order channels.

Figure 3 illustrates the hierarchy of the drainage network of the Tomé-açu micro region. According to Veiga *et al*. (2013) this analysis allows us to identify the interconnection of the channels and, mainly, makes it possible to make analogies about the paths of the river segments and their tributaries, such as, for example, the river segments that will transpose the palm oil plantations. In other words, with the natural organization of the MRGTA rivers, we show the order of smaller volume of water, coming from the water cycle to the more flowing rivers, such as the Moju River and the Acará River. Also, the figure below illustrates the elliptical shape of the sub-watersheds of this micro region, which facilitates its flow from uniform precipitation, thus producing a lower probability of flooding.

Figure 3 - Channel hierarchy in the Tomé-açu Micro Region sub-watersheds.



Fonte: Channel hierarchy in the Tomé-açu Micro Region sub-watersheds.

PALM OIL CULTIVATION IN THE SUB-WATERSHEDS OF THE TOMÉ-AÇU MICRO REGION

When we analyze the territorial dynamics of palm oil cultivation, we face the lack of discussion about the use of water resources in the production of this oilseed. Studies have been limited to palm oil cultivation and its focus is rainfall and favorable water balance. Silva (2003) mentions that “palm oil is a very demanding plant in soil water, and little tolerant to water deficiencies [...] considering that places with water deficiencies below 100 mm are the most suitable for the cultivation of this plant".

Kaltner *et al*. (2004) do not include water among the main inputs in the palm oil agroindustrial chain, which for them are: germinated seeds, fertilizers, pesticides, diesel oil and electricity. The same understanding is held by Furlan Júnior *et al*. (2006), who consider in the palm oil agroindustry, besides the described inputs, the size and structure of the farms. In addition, the assumptions for calculating the energy balance of biodiesel from palm oil include, for example: labor, diesel costs, fertilization, limestone, boron, the amount of seeds, herbicides, insecticides and transportation costs.

The use of water resources is absent when discussing the “environmental requirements to plant oil palm” (Müller and Alves, 1997), although they mention the water balance, it refers only to the amount and intensity of rainfall. According to the authors, water use does not appear when talking about pre-nursery and nursery. Despite mentioning that “evergreen tree crops are generally considered to be the most suitable for humid tropical regions such as the Amazon, the trees have some attributes that make them suitable for the conditions of high rainfall in relatively poor soils” (Müller and Alves, 1997).

Barcelos *et al*. (1987) do not include the existence of watercourses among the ecological requirements (temperature, precipitation, insolation, soils) for palm oil cultivation. The non-inclusion of water resources is contradictory, as the authors recognize that “the nursery must be located near a water source to feed the seedlings contained therein, according to their needs, which are approximately 80 m³/day/ha nursery during the droughts” (Barcelos *et al*., 1987).

For Barcelos *et al*. (1987), is precipitation "the most important climate element for palm oil growth and production, because palm oil is very demanding in water, not tolerating dry regions". Even so, when it comes to irrigation, recognizing that “the water reserve is sufficient to simplify the organization”, we adopt a rate of three irrigation shifts/week. After irrigation, the water balance should be equal to the easily usable water reserve (Barcelos *et al*., 1987). Andrade (2013) recognizes that among the physical factors favorable to palm oil cultivation is the watershed with abundant water.

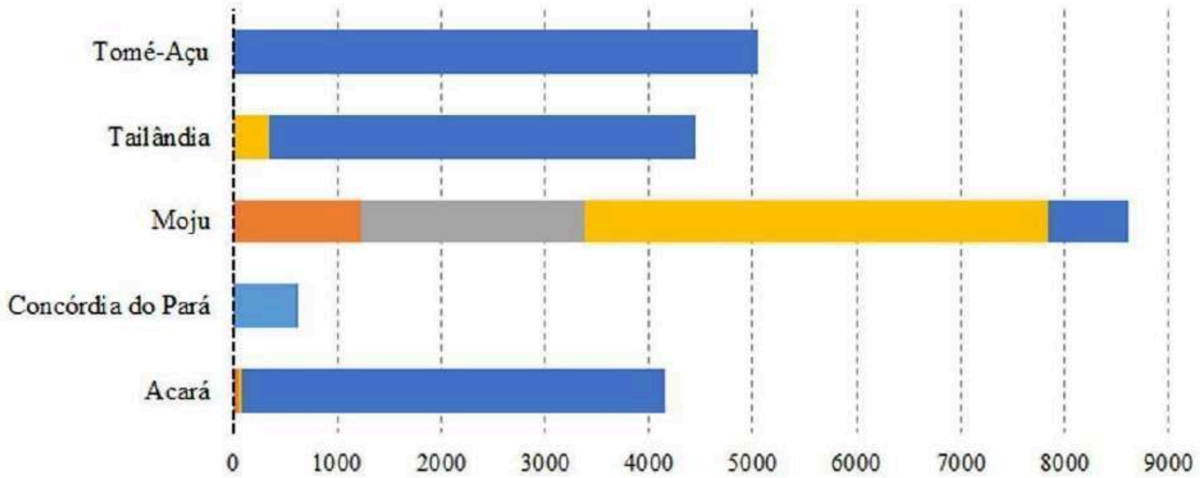
The importance of water in research on palm oil irrigation in the Acará region is strongly emphasized by Veiga *et al*. (2001), who consider water availability has a great influence on leaf size and seasonal variations in the emergence of new leaves, since the fast stretching phase of the floras requires a large amount of water. These variations also affect production, since the rate of formation of new inflorescences follows the rate of emission of new leaves (Veiga *et al*., 2001).

However, when the authors indicate the characteristics required for oil palm cultivation, they point out: location, climate, soil, cover vegetation (Veiga *et al*., 2001); not referring to the water resources and physiographic characteristics of the palm oil cultivation areas in the Amazon. Nevertheless, as important as a good rainfall and water balance are data on: area and shape of watersheds, watercourses, drainage types and networks and drainage density of water bodies (Prado *et al*., 2010), where palm oil crops are located.

In this context, we realize that MRGTA has been undergoing an intense territorial transformation, as a result of the advance of the expansion of palm oil cultivation, which has caused constant changes in the mosaic of the natural landscape of this Amazonian region (Da Silva *et al*., 2016; De Carvalho *et al*., 2014). According to Homma and Vieira (2012), the first palm oil cultivation areas replaced the areas of degraded pastures and abandoned fields over the years. One of the main consequences of the growth of cultivated areas is the changes in the rural landscape, which is now marked by extensive palm monocultures, from public and private institutions, which stand out in the production of palm oil (De Carvalho *et al*., 2014).

In the municipality of Moju are located three of the five sub-watersheds of the Tomé-açu micro region, and in these we find 37.67% (8,612.22 km²) of the *Elaeis guineensis* cultivation areas, highlighting SBH-4 with 4,452.68km² (19.43%) of palm oil fields, followed by SBH-3, SBH-2 and SBH-5, with 2,160.80km², 1,230.67km² and 786,07Km², respectively. In Tomé-açu, the cultivated areas are in the SBH-5 (Acará River), corresponding to the surface of 5.040.90km² (20.98% of the palm). Also on the dividers of SBH-5 there are 61.19% of the total palm oil, distributed in 17.80% of Acará municipality, 17.87% in Tailândia, 3.43% in Moju and 0.06% in Concórdia do Pará, as shown in Figure 4.

Figure 4 - Palm oil area in the sub-watershed of the Tomé-açu micro region in 2018.



	Acará	Concórdia do Pará	Moju	Tailândia	Tomé-Açu
SBH -1	8,5	605,63	0	0	3,92
SBH -2	46,99	0	1.230,67	0	0
SBH -3	0	0	2.160,80	0	0
SBH-4	33,24	0	4.452,68	349,02	0
SBH -5	4.060,81	15,89	768,07	4.094,27	5.040,90

Fonte: Organized by the authors.

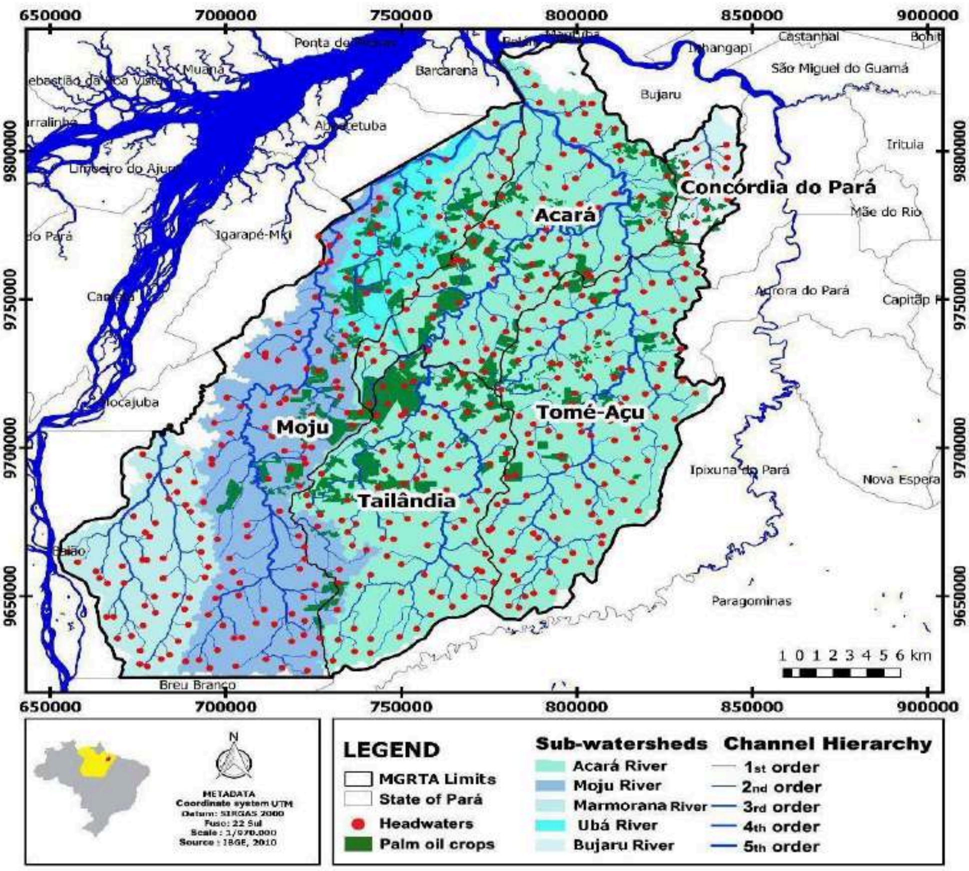
In Figure 4, we observe that the largest perimeter of palm trees is in the municipality of Moju (1,063.80 km), followed by Acará, Tailândia, Tomé-açu and Concórdia do Pará, with 1,008.9 km, 709.36 km, 670, 09 km and 275.19km, in that order. In the following figure, other statistical values of the MRGTA palm oil territory are also highlighted, such as in the Acará River subwatershed (SBH-5) where the average of the palm oil area in the municipality of Tailândia is from 69.71 ha. However, the territory of palm oil has its largest areas of cultivation on the SBH-1 (Acará river) but, it is emphasized that just as water resources do not follow the political-administrative limits, palm oil production Therefore, it does not consider MRGTA SBH interfluves.

Disorders related to the increase of palm oil cultivation areas over the sub-watersheds are mainly related to the increase of agribusiness over the headwater streams, which can decrease soil water storage, causing an increase in lateral flooding and runoff response speed to precipitation, besides influencing the water quality of the microwatersheds (Donadio et *al*., 2005; Francisco et *al*., 2008). Thus, in the region under analysis, there has been an increase in the area of palm oil since the 1980s, and this may result in changes in runoff, infiltration and sediment accumulation over drained areas (Calil et *al*. ,2012).

We identified from orbital data that the Tomé-açu micro region may have more than 489 headwater streams, totaling a APP headwater area (Permanent Protection Area) of 4.89 km², which corresponds to 0.02% of MRGTA. Over the oil palm cultivation territory, we calculated a 0.21km² spring APP area and, along the exposed / anthropized soils, which may serve to expand the *Elaeis guineenses* cultivation areas, we distinguished 0.84 km² of APP headwater area. Overall, the construction process of the Zoneamento Agroecológico do Dendezeiro - Palma de Óleo no Pará (ZAE), an agroecological zoning of palm oil cultivation, had an impact on the MRGTA sub-watersheds, caused by water and soil demands, as well as an increase in the number of grants per project in the municipality (Gomes Ferreira et *al*., 2017).

Figure 5 illustrates the palm oil territory, as well as the headwater streams identified with the applied methodology on orbital data, where we have a top-down view of the five municipalities that make up the MRGTA, the headwater streams and the continuous palm oil monoculture patches, which together total more than 22,870.94 km². Rebello (2012) states that 1 ha of oil palm plantation produces 3 tons of oil. He claims that if all the plantations in the region were at harvest point, they could be producing more than 45,000 tons of oil, which represents 0.05% of the area indicated as suitable by the ZAE.

Figure 5 - Palm oil and headwaters in the sub-watersheds of the Tomé-açu micro region.



Fonte: Organized by the authors.

The greatest concern about the headwaters in crop areas is related to the possibility of contamination of rivers and streams by the intensity of herbicides, fungicides as well as manure (Nahum and Dos Santos, 2014 apud Gomes Ferreira *et al*., 2017). It is also emphasized that some palm oil crops (in the pre-productive phase) near the river sources can cause the deposit of inputs in the riverbed and groundwater, when leached in the rainy season. Soon, the chemicals used in the plantations end up being carried to the waterways, streams and rivers that cross the region. As a result, according to Nahum and Dos Santos (2014), it is the configuration of palm trees as areas of environmental risk, due to possible contamination of water resources, compromising the health of traditional communities in the regions that use these resources. However, it is observed that the evaluated sub-watersheds have presented a dendritic drainage pattern, with diversified drainage density values.

By way of example, in Concórdia do Pará, residents of the Foz do Cravo quilombola community complain of the contamination of streams that cross their areas, whose headwaters are found in BioVale lands, in the municipality of Acará, and flow into the Bujaru river (Carvalho, 2014). Thus, people report health problems such as itching and skin diseases, caused by contaminated water from palm oil planting. According to Nahum and Dos Santos (2014), the environmental risk to water bodies occurs due to the opening of roads and the intensity of herbicides, fungicides, as well as manure in the areas of expansion of palm oil plots. At this point, enforcement needs to be increased to reduce the danger of surface expansion of lawfully protected land.

CONCLUSIONS

From the analysis made in this study, it was found that, although extremely relevant, the increase of oil palm planted area for the economy of the State of Pará may result in changes in the region's ecosystems, especially in the watercourses, which may be indirectly contaminated, since the plantations, such as the municipality of Moju, are placed on the banks of streams, lakes and rivers, therefore, in permanent protection area. From this perspective, it is necessary to increase control in the palm oil production zone to avoid the danger of expansion over legally protected areas, as companies, by introducing their palm oil monoculture plantations, have established significant changes in the land use pattern. This fact leads us to believe that a number of studies on water quality are needed.

The modernization of Pará agriculture has at the same time impacted the social environment, land concentration, decampesinization, as well as the threat to food security and the risk of contamination of watercourses. Thus, palm oil crops can be a threat on water resources, since this crop has changed the landscape, directly reflecting the runoff, temperature distribution, evapotranspiration, rainfall, among other edaphoclimatic components.

However, without appropriate public policies for the sector, palm oil expansion will put pressure on water resources, reducing them over time through the process of siltation or chemical contamination. Therefore, the integrated analysis of water resources, taking into account all sub-basins, can assist in the indication of sustainable alternatives for aquifer exploitation, as well as in the adoption of a soil, water and biodiversity conservation plan, but always taking into account negotiations between users, mediated by river basin committees and public agencies, to avoid inequalities in access to water.

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