ARTHUR AMARAL E SILVA

ANTHROPIC ACTIONS AND THE DEGRADATION OF AMAZON BIOME: STUDIES OF IMPACTS AND SOIL RECOVERY

Dissertation submitted to the Civil Engineering Program of the Universidade Federal de Viçosa in partial fulfillment of the requirements for the degree of *Magister Scientiae*.

Adviser: Júlio César de Oliveira

VIÇOSA - MINAS GERAIS
2021

Ficha catalográfica elaborada pela Biblioteca Central da Universidade Federal de Viçosa - Campus Viçosa

T

S586
2021

Silva, Arthur Amaral e, 1994-

Anthropic actions and the degradation of Amazon biome : studies of impacts and soil recovery / Arthur Amaral e Silva. – Viçosa, MG, 2021.

72 f. : il. (algumas color.) ; 29 cm.

Inclui apêndice.

Orientador: Julio Cesar de Oliveira.

Dissertação (mestrado) - Universidade Federal de Viçosa.

Inclui bibliografia.

1. Desmatamento - Amazônia. 2. Solo - Uso - Amazônia. 3. Áreas degradadas - Recuperação - Amazônia. 4. Mudanças climáticas. 5. Análise de séries temporais. I. Universidade Federal de Viçosa. Departamento de Engenharia Civil. Programa de Pós-Graduação em Engenharia Civil. II. Título.

CDD 22. ed. 333.751309811

ARTHUR AMARAL E SILVA

ANTHROPIC ACTIONS AND THE DEGRADATION OF THE AMAZON BIOME: STUDIES OF IMPACTS AND SOIL RECOVERY

Dissertation submitted to the Civil Engineering Program of the Universidade Federal de Viçosa in partial fulfillment of the requirements for the degree of *Magister Scientiae*.

APPROVED: March 11, 2021.

Assent:

Arthur Amaral e Silva
Author

Júlio César de Oliveira
Adviser

ACKNOWLEDGMENTS

Primeiramente, gostaria de agradecer a Deus pelas oportunidades dadas a mim e por me dar força, perseverança, saúde e me proporcionar estar concluindo mais etapa da minha vida.

Agradeço também aos meus pais, Solange Amaral e Carlos Silva, pelo amparo, companheirismo, amor e por sempre estarem do meu lado não podendo ser presentes no meu dia a dia. Obrigado.

Agradeço ao meu irmão, Matheus Amaral, por sempre ter me dado o apoio necessário para seguir em frente e por ser essa pessoa maravilhosa que é a extensão do meu coração. Eu te amo. Obrigado.

Ao professor Júlio César de Oliveira, agradeço pela orientação e acompanhamento durante esses dois anos de trabalho. Poder ter a oportunidade de desenvolver pesquisa com este grande mentor me proporcionou crescimento pessoal e aprendizagem para a vida. Obrigado.

Agradeço a professora Lúcia Calijuri, que desde minha chegada à Universidade Federal de Viçosa, no primeiro contato com a disciplina ministrada por ela, me acolheu, me ensinou, me orientou, me proporcionou acesso a coisas e experiências imensuráveis e engrandecedoras. Sem ela este caminho trilhado não seria o mesmo. Obrigado.

Aos meus amigos de Fortaleza, Bruno Calixto, Paulo Santiago, Roberta Amélia, Luiz Fernando, Ivna Milério e Gustavo Tavares, que mesmo com a distância se fizeram presentes e me ajudaram a seguir nesta jornada árdua, porém gratificante. Obrigado

Ao meu amigo (irmão), Lucas Rodrigues, e minha prima (irmã/melhor amiga), Luiza Helena, por serem essas pessoas maravilhosas que me dão força todos os dias, se fazem presentes a cada instante e que são uma grande parte de mim e de tudo que sou. Sem vocês eu não teria chegado aqui. Cada puxão de orelha, conselho, abraço, mensagem, e tudo que já passamos me fortificou e me trouxe até este momento. Obrigado.

Aos meus amigos de Viçosa, minha família que construí aqui, Iara Magalhães, Alexia Aona, Matheus Quintão, Thiago Abrantes, Daniel Louzada e Gustavo Milião. Agradeço por toso apoio nos momentos difíceis, por cada abraço, cada momento de confraternização e por toda foça que compartilhamos para seguirmos em frente e conquistar nossos sonhos. Obrigado.

Ao meu namorado, Marcelo Filho, que me acompanhou desde o início desta jornada, quando tudo começou em 2019 e me deu força todos os dias para continuar e seguir de cabeça erguida. Você esteve comigo em todos os momentos e nunca me deixou sentir sozinho. Amar você é grande parte de mim e sua reciprocidade me engrandece e me torna uma pessoa melhor todos os dias. Eu te amo, pandinha, Obrigado.

À equipe do laboratório SIGEOnPA, agradeço por todo suporte e companheirismo, e a. Em especial, gostaria de agradecer aos companheiros de trabalho Vitor Juste (Tio Vitor) e Juliana Lorentz (Ju), por terem me acompanhado, me orientado academicamente e pessoalmente, por todo ensinamento e por fazer desta jornada um pouco mais fácil e prazerosa. Obrigado.

À Universidade Federal de Viçosa, pela oportunidade de realizar a pós-graduação.

À Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), pela concessão da bolsa de estudos. O presente trabalho foi realizado com apoio da Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Código de Financiamento 001.

Por fim, gostaria de agradecer a todos que de alguma forma, seja diretamente ou indiretamente, fizeram e fazem parte desta caminhada e que contribuíram para que tudo isso possa estar acontecendo. Obrigado.

"And in this moment, I swear,

We are infinite"

The Perks of Being a Wallflower

ABSTRACT

AMARAL E SILVA, Arthur, M.Sc., Universidade Federal de Viçosa, March, 2021. **Anthropic actions and the degradation of the Amazon biome: studies of impacts and soil recovery**. Adviser: Júlio César de Oliveira.

This study aimed to evaluate the impacts caused by the forms land use and occupation of the Amazon biome and the reflexes of these impacts in the regional, national and global climatic scenario. As well as, studying ways to recover these degraded areas aiming at the return of these environments to their natural state and, with that, the generation of income for the local population, which are the main ones affected by the effects of deforestation in the region. To achieve the objectives of this study, it was divided into three chapters: (i) Human activities and the Legal Amazon: estimation of impacts on the forest and the regional climate; (ii) The vulnerability of the Amazon biome: how anthropic actions contribute to climate change over time based on PCA and STA analyzes; (iii) Oilseed cultivation in degraded areas in the Legal Amazon for soil recovery and biodiesel production. Data processing took place entirely in a Geographic Information System (GIS) environment, in which the databases obtained were standardized and analyzed according to the need for each chapter of this study. The first two chapters aimed to analyze the impacts that human activities cause on climatic conditions in the Amazon biome. In this context, the interfaces Land Change Modeler (LCM) and Earth Trends Modeler (ETM), from the Idrisi Selva software, were used. It was possible to conclude that activities such as pasture, agriculture and livestock, are the ones that most cause deforestation in the Amazon biome and within the limits of the Legal Amazon, a region that also covers part of the Pantanal and Cerrado biomes. This deforestation, caused by anthropic actions, directly impacts on local climatic conditions, changing patterns of rainfall and temperature, which in turn, cause climatic disturbances at national and global level since the Amazon is the largest and most important tropical forest in the world and has important functions within the earth's hydrological cycle. Chapter three aimed to identify areas suitable for the cultivation of oilseeds aiming at the recovery of degraded areas and the production of biodiesel. In this, two species were compared, *Elaeis guineenses*, popularly known as Dendê, and *Jatropha curcas* also known as Pinhão Manso. Both crops are suitable for the recovery of degraded areas and have a high capacity for biodiesel production, in addition to being endemic species in the region. After producing the study, it was possible to conclude that the Amazon biome constantly suffers from external pressures, which vary from the urbanization process to the insertion of agriculture and livestock. These pressures have the main consequence of increasing deforestation rates, generating changes in the natural landscape and changes in climatic conditions. Due to the gravity of the current scenario of the Amazon biome and its importance on the world stage, the preservation and recovery of this area becomes a necessity. Public policies aimed at protecting the Amazon must be created, and the existing ones, intensified, seeking to delay the impacts of man in this region and providing the return of the forest to its natural state.

Keywords: Legal Amazon. Anthropic activity. Deforestation. Time series analysis. Climate change. Soil Recovery.

RESUMO

AMARAL E SILVA, Arthur, M.Sc., Universidade Federal de Viçosa, março de 2021. **Ações antrópicas e a degradação do bioma Amazônia: estudo dos impactos e recuperação do solo.** Orientador: Júlio César de Oliveira.

Este estudo teve como objetivo avaliar os impactos causados pelas formas de uso e ocupação do solo do bioma Amazônia e os reflexos destes impactos no cenário climático regional, nacional e global. Objetivou também, estudar formas de recuperar estas áreas degradadas visando o retorno destes ambientes ao seu estado natural e, com isso, a geração de renda para a população local, principal atingida pelos efeitos do desmatamento na região. Para alcançar os objetivos propostos, o mesmo foi divido em três capítulos: (i) Atividades antrópicas e a Amazônia Legal: estimativa dos impactos na floresta e no clima regional; (ii) A vulnerabilidade do bioma Amazônia: como ações antrópicas contribuem para as mudanças climáticas ao longo do tempo com base em análises de PCA e STA; (iii) Cultivo de sementes oleaginosas em áreas degradadas na Amazônia Legal para recuperação de solo e produção de biodiesel. O processamento dos dados ocorreu em ambiente de Sistema de Informações Geográficas (SIG), que padronizou e analisou as bases de dados de acordo com a necessidade de cada capítulo deste estudo. Os dois primeiros capítulos tiveram como objetivo analisar os impactos que as atividades antrópicas causam nas condições climáticas do bioma Amazônia. Neste contexto, foram utilizadas as interfaces *Land Change Modeler* (LCM) e *Earth Trends Modeler* (ETM), do software Idrisi Selva. Foi possível concluir que atividades como pastagem, agricultura e pecuária, são as que mais causam desmatamento no bioma Amazônia e dentro dos limites da Amazônia Legal, região que cobre também parte dos biomas Pantanal e Cerrado. Este desmatamento, causado por ações antrópicas, impacta diretamente nas condições climáticas locais, alterando padrões de pluviometria e temperatura, que por sua vez, acarretam distúrbios climáticos a nível nacional e global uma vez que, a Amazônia é a maior e mais importante floresta tropical do mundo, e possui funções importantes dentro do ciclo de hidrológico da terra. O capitulo três teve como objetivo identificar áreas adequadas para cultivo de oleaginosas visando a recuperação de áreas degradadas e a produção de biodiesel. Neste foram comparadas duas espécies, *Elaeis guineenses* (Dendê) e *Jatropha curcas* (Pinhão Manso). Ambos cultivos são adequados para recuperação de áreas degradadas e possuem alta capacidade para produção de biodiesel, além de serem espécies endêmicas da região. Após produção do estudo, foi possível concluir que o bioma Amazônia sofre constantemente por pressões externas, que variam desde o processo de urbanização a inserção da agropecuária. Estas pressões têm como principal consequência o aumento das taxas de desmatamento, gerando modificações na paisagem natural e alterações nas condições climáticas. Devido à gravidade do cenário atual do bioma Amazônia e importância deste no cenário mundial, a preservação e recuperação desta área se torna uma necessidade. Políticas públicas voltadas a proteção da Amazônia devem ser criadas, e as existentes, intensificadas, buscando o retardamento dos impactos do homem nesta região e proporcionando o retorno da floresta ao seu estado natural.

Palavras-chave: Amazônia legal. Atividade Antrópica. Desmatamento. Análise de séries temporais. Mudanças climáticas. Recuperação de solos.

SUMMARY

GENERAL INTRODUCTION

The Amazon rainforest represents the largest tropical forest on Earth, covering an area of approximately 6.5 million km2. It corresponds to 56% of the world's tropical forests and is present in 9 countries, with Brazil being responsible for 50% of the total area of the Amazon biome (Barlow et al., 2011; Rosa et al., 2013; Farias et al., 2018). About a quarter of the world's terrestrial species are found in the biome and, according to the literature, it is responsible for approximately 15% of total terrestrial photosynthesis (Dirzo & Annu, 2003; Farias et al., 2018).

Created by Law 1,806 of 1953 and updated to its current format by Complementary Law No. 31 of 1977, the Legal Amazon corresponds to an area of approximately 5.2 million km² that encompasses nine Brazilian states and covers about 61% of the national territory (IBGE, 2014). This area comprises, in addition to the Amazon rainforest, two other important biomes, Pantanal and Cerrado (Filho and Souza, 2009).

Legal Amazon has suffered environmental impacts associated with high levels of degradation, generated by agricultural growth, increased extractive trade and the impacts of urban expansion (Ferreira et al., 2015). The growth of agricultural activity in Brazil has created serious environmental problems in the country's natural landscapes. This is the biggest cause of degradation within the Legal Amazon area, being responsible for about 40% of the degraded areas or in the process of degradation, in addition to contributing almost 70% of the total greenhouse gas emissions (Veloso et al., 2010). About 20% of the degraded areas of the Legal Amazon are the result of the expansion of the agricultural frontier. Deforestation, caused by the intensification of this expansion, already covers an area of 77,520 km² (68% of the total deforestation), with pastures accounting for 28% of the deforestation (32,120 km²) (IBGE, 2015). These uncontrolled levels of deforestation are close to reach the limit that will provide irreversible changes in the natural patterns of the forest (IPAM, 2017).

Several authors discuss the relationship between climate and forest formation in the Amazon (Fisch et al., 1998; Andreola Serraglio et al., 2019; Molion, 1987; Alves, 2018; Santos et al., 2017). This relationship has different aspects, two of which are widely used in studies. One states that climate is directly associated with the natural state of the forest. Another argues that climatic conditions dictate forest formation.

According to Salati and Ribeiro (1979), the forest cover of a region is, in a way, a consequence of the climate and the soil. However, due to factors such as the impact of deforestation on local rainfall and thermal conditions and the water control of the forest to be carried out in about 50% by evapotranspiration, it is stated that Legal Amazon' climate is directly linked to forest formation, depending on this semi-integral form for its variations (SALATI & RIBEIRO, 2019).

In this work we tried to analyze the variations that occurred in the climate, in the natural vegetation and in the level of anthropic action, through a temporal study of the Legal Amazon and Amazon biome area, associating these variations to the impacts that occurred in the area. Based on these associations, in addition to identifying existing degraded areas, we sought to provide a form of recovery with the cultivation of oilseeds, in an attempt to reverse the current situation of degradation presented and provide greater socioeconomic power to the region.

Chapter 1 - Anthropic activities and the Legal Amazon: estimative of impacts on forest and regional climate

Abstract

Created by the Law 1,806 of 1953 and updated to its original format by the Complementary Law Nº. 31 of 1977, the Legal Amazon covers an area of approximately 5.2 million km², covering nine Brazilian states, corresponding to around 61% of all Brazilian territory. In addition to the Amazon biome, the Legal Amazon covers part of Cerrado and Pantanal biomes. This region has suffered several impacts caused by the introduction of anthropic activity, mainly agriculture, leading it to have a high rate of deforestation. As a way to mitigate the impacts in these areas, this paper aims to identify the possible variations in climatic variables and in the Legal Amazonian Normalized Difference Vegetation Index (NDVI), generated from the growth of anthropic action. As well as to outline the predicted deforestation scenario and the anthropic activity for 2030, allowing an association between the growth of impacts, the aforementioned variations and the level of degradation. To achieve the aims outlined here, the methodology is divided into 3 steps: definition of the study area, data collection and standardization, and processing and comparison of the data obtained (using the Land Change Modeler and Earth Trend Modeler interfaces). The results of this research corroborate to observe that, in the Legal Amazon, the forest has control over the climate. Changes caused by increased levels of anthropogenic action have a direct impact on vegetation; increase deforestation rates and causes variations in temperature and rainfall. It concluded that the non-adoption of actions to control natural vegetation removal increases deforestation, causing greater changes in NDVI levels, greater changes in the hydrological cycle and thermal control.

Keywords: Legal Amazon, Anthropic activity, Deforestation, Time series analysis, Climate change.

1. Introduction

The Legal Amazon, created by the Law Nº 1,806 of 1953 and updated to its current format by the Complementary Law Nº. 31 of 1977, corresponds to an area of 5,217,423 km² covering nine Brazilian states, which corresponds to about 61% of the national territory (IBGE, 2015). Such delimitation includes, besides the Amazon rainforest, part of the Pantanal and Cerrado biomes (Filho and Souza, 2009). This area has suffered great impacts through the insertion of anthropic activities, leading to a deforestation rate, in 2018, higher than 7,500 km², with state of Pará hit the hardest (Barbosa and Lakshmi Kumar, 2016).

According to Ferreira and Coelho (2015), deforestation in the Legal Amazon relates to several factors, among them, commercialization of agricultural products, failing government policies, impacts of urban expansion, increased agricultural activity and arson. Agricultural activity, responsible for about 40% of degraded or undergoing degradation areas, contributes to almost 70% of total greenhouse gas emissions (Veloso et al., 2010), and stands out in the increase of Legal Amazon degradation. Logging is one of the most profitable economic activities of states within the limits of the Legal Amazon, and is responsible for vegetation removal (Kingo and Homma, 2015).

Nóbrega (2014) states that intense extraction of natural vegetation in the Amazon can cause irreversible regional, national and global damage, since such removal may affect rainfall regime, as well as result in temperature variations.

Several authors discuss the relationship between climate and forest formation in the Legal Amazon (Molion, 1987; Fisch et al., 1998; Santos et al., 2017; Alves, 2018; Andreola Serraglio et al., 2019), bringing different opinions on the subject. Some claim that rainfall and temperature are directly associated with the forest's natural state. Others affirm that climatic conditions determine forest formation.

Salati and Ribeiro (1979) and Higuchi and Higuchi (2012) state that, a region's forest cover is, somehow, a consequence of climate and soil. On his work, Copertino et al. (2019) reinforces the aforementioned statement affirming that changes on natural landscape, as deforestation, causes irreversible changes on local and global climate. Climate is directly linked to forest formation in Amazon biome, depending on it semi-integrally for its variations (Fearnside, 2008). This statement is due to the impact of deforestation on local rainfall and thermal conditions and that forest hydrologic control depends about 50% on evapotranspiration (Salati and Ribeiro, 1979).

Human actions that contribute to changes in natural landscape coverage are capable of altering the microclimate (Buckeridge and Ribeiro, 2018). Such actions reduce forest evapotranspiration, generate greater energy accessible to the atmosphere and increase air temperature (Malhi et al., 2008). With evapotranspiration reduction, it is likely that precipitation will decrease, since it comes from the local water vapor released from forest surface and is transported by air masses movement (Rocha et al., 2017).

Alves (2018)states that the movement of air masses can directly affect an area's hydrologic regime, since they move from one region to another, carrying and distributing rain. Continental Equatorial (cE) air mass, originated in the Amazon, plays a fundamental role in transporting moisture to other regions in the country, due to the high evapotranspiration process that occurs in the forest. Rain formation depends directly on natural vegetation and, therefore, plant extraction impacts on the water loading of air masses (Farias et al., 2018).

Numerous tools are applicable to analyze factors that can contribute to climate and soil changes. Geographic Information Systems (GIS) enable temporal and spatial study of changes in natural conditions that contribute to imbalances that affect their degradation levels (Gašparović et al., 2018).

GIS allow the aggregation of spatial information on maps, as well as processing, analyzing and relating data that contribute, for example, to the identification, implementation and management of areas, allowing the analysis of rainfall, temperature and vegetation cover historical series. As well as the production of prediction maps of future degradation conditions and urbanization (Pondorfer, 2019). In this context, the aggregation of the data above-mentioned allows to quickly reach the goals of this work.

This study aimed to identify possible variations in rainfall, temperature and Normalized Difference Vegetation Index (NDVI) of the Legal Amazon, generated from the anthropic action increase. At the same time, outline a deforestation prediction scenario for anthropic activity for the year 2030, allowing an association between the impact increase, the aforementioned variations and the level of degradation.

2. Material and Methods

To achieve the aims of this work, methodology was divided into 3 sections (Figure one):

1. Study area definition;
2. Database collection and standardization;
3. Database processing and comparison.

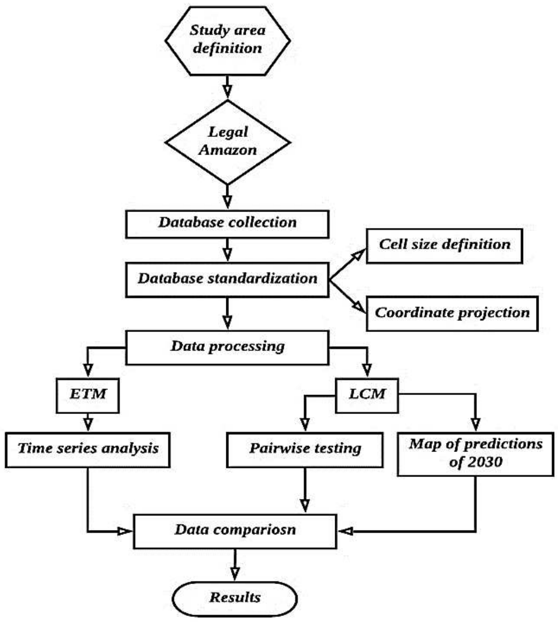

Figure 1: Methodological scheme

2.1 Study area definition.

According to the Brazilian Institute of Geography and Statistics (IBGE), the Legal Amazon is an area of 5.2 million km², which corresponds to 61% of the Brazilian territory (Figure 2). It covers the entire Brazilian Amazon biome, as well as 20% of the Cerrado biome and part of the Pantanal Mato-grossense. The states of Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima and Tocantins are completly inserted in this region, which also cover part of Maranhão.

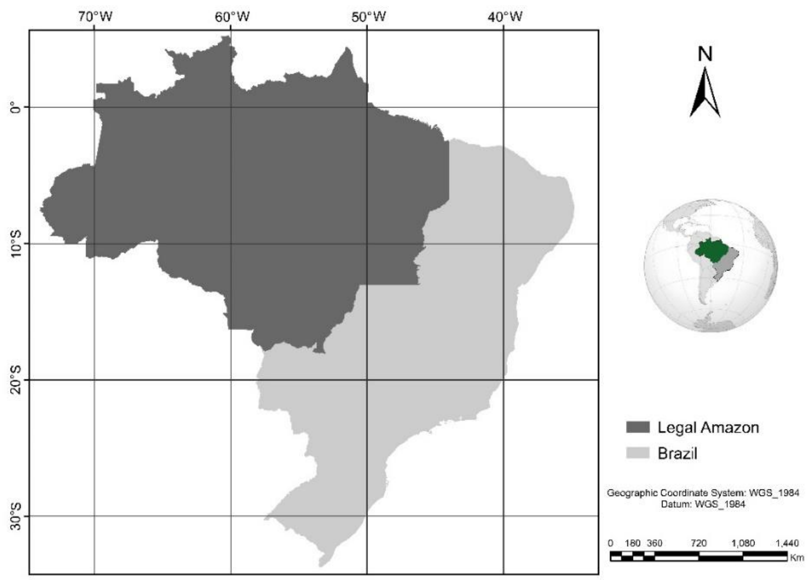

Figure 2: Study area

Rocha et al.(2019) affirm that, the study area is located in an equatorial region that presents a hot and humid climate, with an average temperature around 25ºC, and low variation over seasons. The region has an average rainfall of approximately 2300 mm/year, where about 50% comes from evapotranspiration in the Amazon basin itself.

Legal Amazon has a diverse geomorphology, characterized by a relief composed predominantly by plateaus, plains and depressions. Amazon plain covers around 7% of the region's total, while almost 74% of the territory is formed by visibly irregular terrain. The soil in this area is sandy featured, with a thin O-horizon, rich in humus that comes from the large amount of organic matter deposited by the forest, but poor in nutrients because it has a high rate of decomposition (Florenzano, 1996; Sales et al., 2018).

Related to vegetation, as it incorporates three biomes within its limits, the study area presents firm land areas, floodplain and igapó forest, part of the section covered by Amazon biome (Mello and Artaxo, 2017). In the Cerrado side, there are parts similar to savannas, with low and sparse trees, twisted trunks, thick leaves and long roots, grasses and shrubs (Liesenfeld et al., 2017). In addition, medium-sized trees and creeping plants can also be found within the Pantanal section (Felfili et al., 1998; De Oliveira Mota et al., 2018).

2.2 Database collection and standardization

The data used were collected from free sources and made available by the agencies listed in Table 1.

Table 1: Data source, time series and scale

Data	Data source	Time series	Resolution
Rainfall	Chelsa	1981 - 2013	1:1km
Temperature	Chelsa	1981 - 2013	1:1km
NDVI	NASA	1981 - 2013	1:5km
Land use	MapBiomas	1985 - 2017	1:30m
Deforested areas	INPE - PRODES	2005 - 2017	1:500m

For database standardization, it used ESRI's ArcGis® version 10.5 software.

2.3 Database processing and comparison

After database standardization, it proceeded to processing step, performed using Clark Labs' Idrisi Selva® version 17.0 software. Used the Land Change Modeler (LCM) and Earth Trend Modeler (ETM) interfaces, applicable to studies of changes in land cover and land use conditions and biodiversity, and variations within a historical data series, respectively (Figure 3).

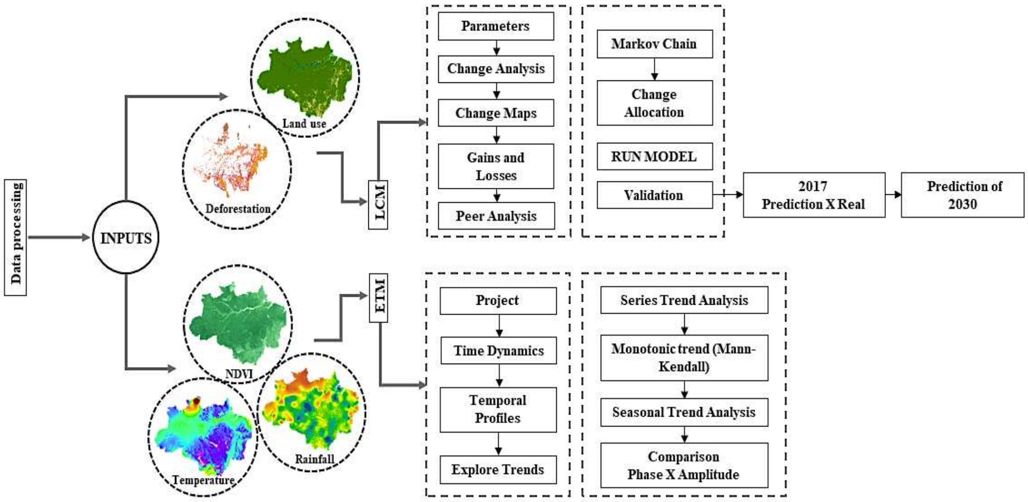

Figure 3: ETM and LCM data processing

2.3.1 Land Change Modeler

LCM is an IDRISI software environment used to analyze land use conversion trends as well as assessing specific biodiversity conditions. It first used this interface to compare, from 1985 to 2013, changes in natural vegetation as a function of anthropic activities. It is noteworthy that, since the temporal study began in 1981, the data prior to 1985, the range from 1981 to 1984, came from the software Excel 2016 applying Forecast algorithm.

The Forecast technique calculates a new value from existing values, where predicts the new value by linear regression (Office, 2016). Pellegrini and Fogliatto (2001) state that forecasting techniques make it possible to perform mathematical modeling using existing data, allowing precise calculations.

Land use and deforestation data were predicted, generating information about future conditions presented in the study area, simulating the anthropic action and deforestation dimensions of the Legal Amazon in 2030. For the prediction function, it used inducing variables (Table 2), which direct possible changes over time.

Table 2: Change-inducing variables

Inductive Variable	Year	Data source	Resolution	Type
Roads	2017	DNIT	1:5Km	Static
Railways	2017	FOREST-GIS	1:5Km	Static
Waterways	2017	FOREST-GIS	1:5Km	Static
Agriculture	1985 - 2017	MapBiomas	1:5Km	Dynamic

Livestock	1986 - 2017	MapBiomas	1:5Km	Dynamic

Within the LCM interface, it used the 2005 and 2011 maps for model calibration. After calibration, it made he forecast for 2017. Using the actual map of the same year, prepared by MapBiomas, it validated the model. From this result, the forecast map for 2030 was prepared.

Applying the CROSSTAB algorithm between the maps used to validate the model, it obtained a Kappa index of 77%. According to Viera and Garrett (2005), a Kappa value below 40% has low quality, requiring data reformulation; values between 40 and 70% indicate moderate but pending review data; values between 70 and 75% reflect good quality data and values above 75% demonstrate high quality analysis. Thus, the model applied here is applicable to use with high quality.

2.3.2 Earth Trend Modeler

The Earth Trend Modeler (ETM) interface analyzes trends and dynamic characteristics of time series by imagery. These series provide a critically important resource for understanding the dynamics and evolution of environmental phenomena.

This work used the interface to analyze the time series variations of NDVI, rainfall and temperature data, to understand and monitor the databases behavior, generating graphs for later comparison. The period from 1981 to 2013 was selected because it presented better data interpolation, allowing higher quality results.

One of the performed analysis was the Mann Kendall (MK) test. A robust, sequential, nonparametric method applied to determine whether a specific data series has a statistically significant trend within a given time series (Mann, 1945). This method is suggested by the World Meteorological Organization (WMO) to assess the trend in time series of environmental data (Lopes and Silva, 2013).

The Mann-Kendall test is applied in time series without seasonality and performed individually on each pixel (Güçlü, 2018). Neighboring pixels may have opposite behaviors. This test presents a range of -1 to 1, with the negative extreme indicating a decrease in the variable, the positive extreme indicating an increase in the studied variable and 0 indicates a balance between losses and gains (Sayyad et al., 2019).

Since it is a nonparametric method, it does not require normal data distribution (Yue et al., 2002). Another advantage presented by MK test is that it is little influenced by abrupt changes or inhomogeneous series (Zhang et al., 2009). However, this method requires data to be independent and random (Neeti and Eastman, 2011; Salviano et al., 2016).

For greater precision regarding the association of variables, the correlation test was also applied because, according to Santos and Toledo Filho (2014), to measure the degree of association between the variables, the correlation coefficient must be used. The correlation coefficient result gives the association level (ρ), which varies from 1 to -1 (Table 3). The coefficient presents a two-tailed relationship, that is, closer the extremities values, 1 or -1, higher the correlation/association. When $\rho = 0$ there is no correlation. This coefficient presents descriptions that, according to the variety of values, can range from Strong Positive, directly proportional variables, to Strongly Negative, inversely proportional variables (Santos and Toledo Filho, 2014).

Table 3: Correlation coefficient adapted from Santos and Toledo Filho (2014)

ρ value (+ or -)	**Description**
0 – 0.19	Very week correlation
0.20 – 0.39	Week correlation
0.40 – 0.69	Moderately correlation
0.70 – 0.89	Strong correlation
0.90 – 1.00	Very strong correlation

The Correlation Test was applied to verify the correlation between NDVI, temperature and rainfall. Thus, it was possible to verify whether the variables are directly or inversely proportional and to observe the interaction behavior between each factor.

3. Results

3.1 Factors Interaction and Their Impacts on the Legal Amazon

The results obtained confirm the statement made by Salati and Ribeiro (1979) and Higuchi and Higuchi (2012) that in the Legal Amazon the forest interferes directly in the climatic conditions.

Earth Trend Modeler, based on time series analysis, evaluated the amplitude of each variable. Representative graphs of the variation trends in the adopted time interval for NDVI, rainfall and temperature were obtained.

In the study area, it can be observed that the anthropic action varies directly proportional to temperature, and inversely proportional to NDVI, which, in turn, is directly proportional to rainfall. Figure 4 presents the trend graphs of the analyzed variables on ETM, as well as the section selected to verify the correlation.

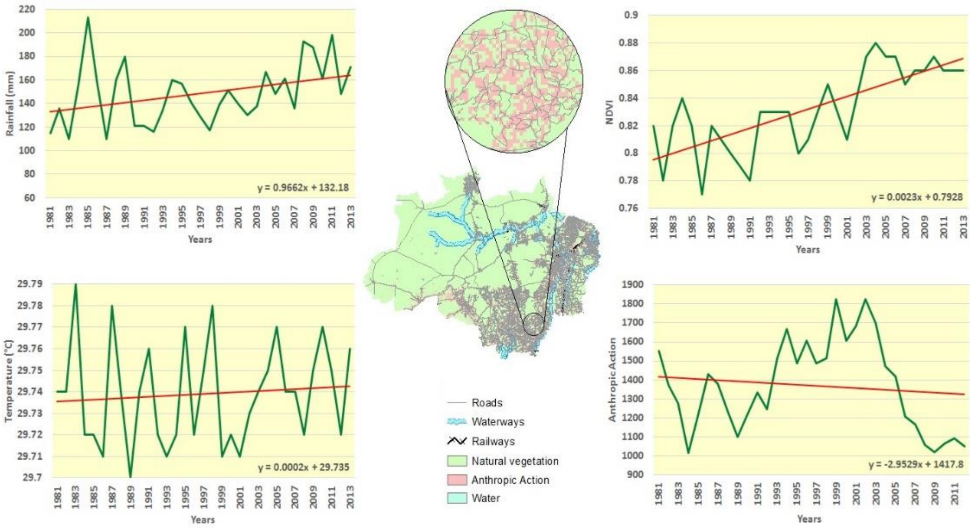

Figure 4: Section selected for analysis of variation ranges

Graphical construction within the interface is performed by choosing a specific section of the amplitude map, allowing the entire series to be analyzed. The variation graph is obtained, accompanied by the change trend line. This section was chosen because it presents relevant interaction of the roads, inserted as driver of change, with the areas of occurrence of anthropic action.

Graphical analyzes show that, from 1981 to 2013, the Legal Amazon underwent changes in vegetation cover, rainfall and thermal control, caused by changes in the natural landscape resulting from anthropic action in this area. Analyzing the trend line, was possible to see that, in this period, the anthropic action tended to decrease, while NDVI and rainfall showed a tendency to increase and the temperature remained close to constant variation.

From the Mann-Kendall test, it was concluded that the environmental variables present correlated behavior. Within the area affected by anthropic activity, there was a negative variation for NDVI, indicating its decrease in this area. Rainfall also generated data closer to the negative tail of the test, representing a decrease in rainfall levels. Temperature showed positive behavior, representing an increase of this variable in the affected areas (Figure 5).

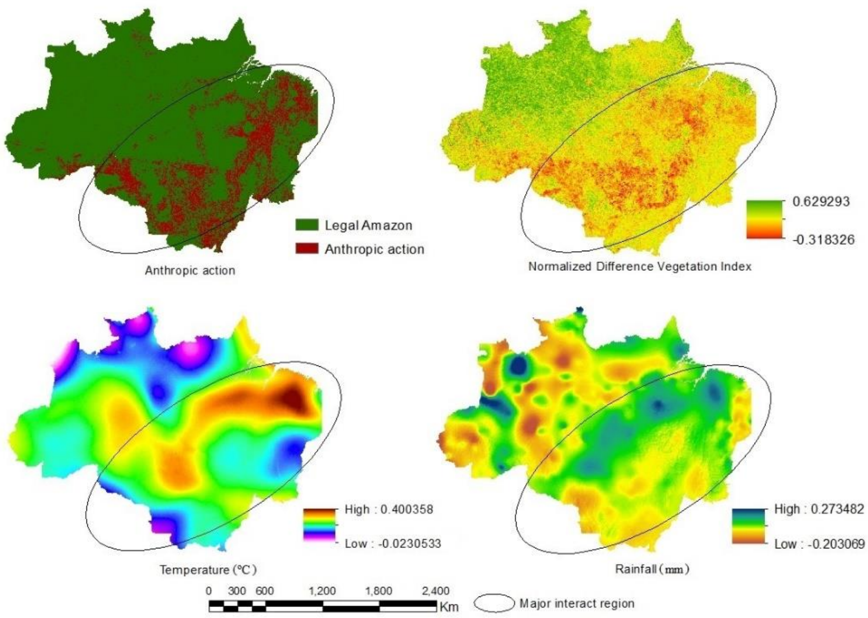

Figure 5: Analysis of Mann-Kendall test in areas with higher anthropic activity

As a complement to the Mann Kendall test, the Correlation Test was performed (Figure 6), allowing a better characterization of the studied variables.

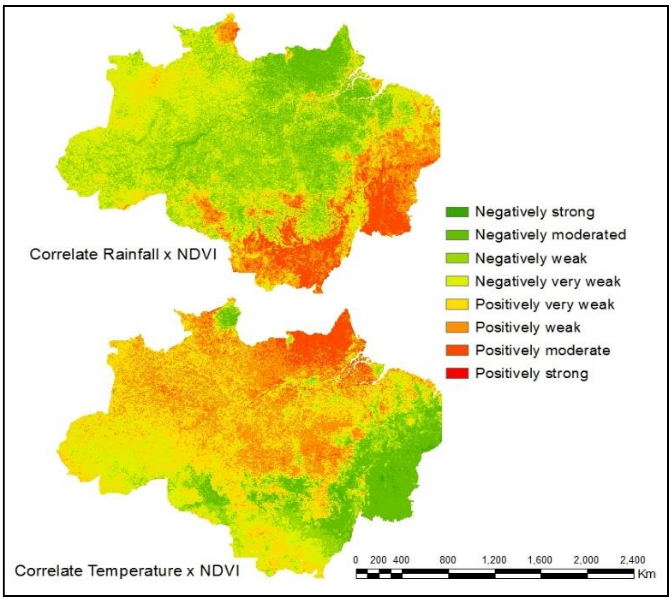

Figure 6: Correlation map between the variables

Analyzing the maps, figure 6 shows that NDVI has a moderately positive correlation with rainfall, indicating that these two variables are directly proportional, with linear behavior. The same does not occur in relation to temperature, since, when associated with NDVI, it has a moderately negative correlation, indicating that these variables are inversely proportional, varying nonlinearly. Thus, it was observed that the vegetation cover in the Legal Amazon area has direct interference with the local climatic conditions, which, in turn, interferes with the global climate.

3.2 2030 Area Scenario: Reflection of Natural Landscape Usage

Within the Land Change Modeler interface of the Idrisi software, the study area conditions were predicted as a function of the anthropic activity for the year 2030 (Figure 7). There was an increase in the number of areas with presence of anthropic activity, therefore, increase in deforested areas and reduction of natural forest.

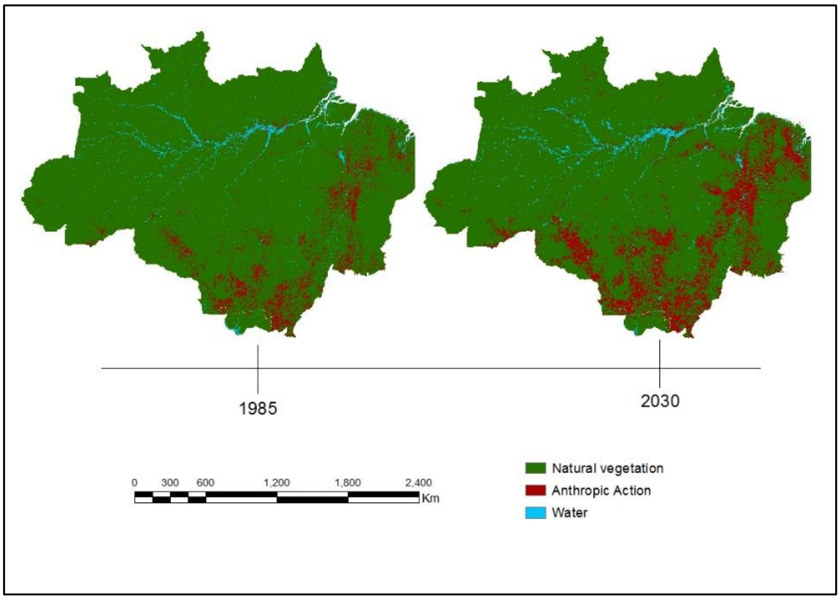

Figure 7: 2030 forecast land use map

Year 2030 was chosen since, according to the Northern Sustainable Development Report 2030, land regularization of territories within the Legal Amazon is expected.

From the analysis performed, between 1985 and 2030, the anthropic action presented growth of 354%. This represents an increase of 336,000 km^2 of land use over a 45-year interval. Thus, it is possible to conclude that in this area, anthropic activity will cover about 12% of the total area of the Legal Amazon by 2030. This result shows a growth of 7% when compared to the reference year, 1985, where it extended to 5% of the territory of the Legal Amazon.

Regarding deforestation levels (Figure 8), as they are inserted in the growth arc of human activities, they also tend to grow within the forecast for 2030. Anthropic actions that alter the natural landscape cause vegetation suppression, leading to an increase in deforested areas (IPAM, 2017).

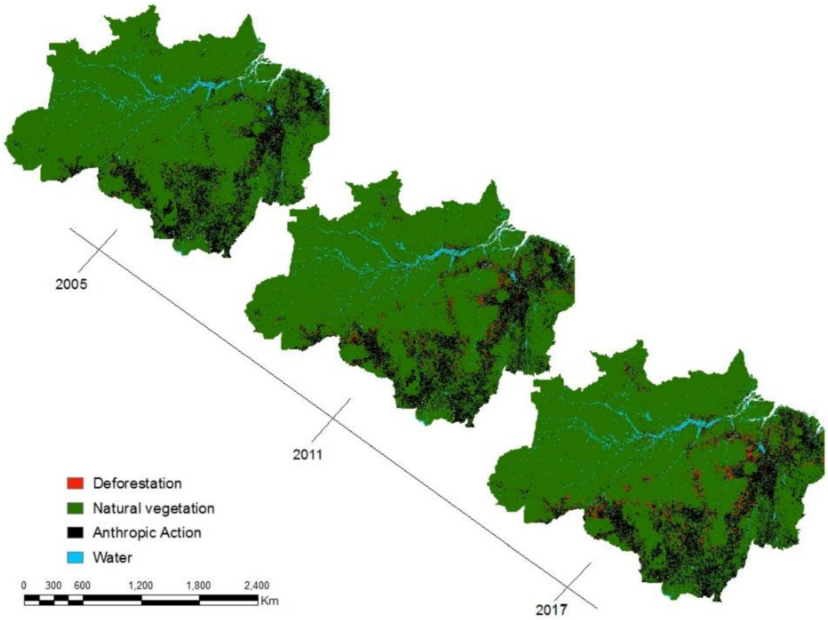

Figure 8: Deforested areas of the Legal Amazon

4. Discussion

Crossing the information generated by LCM and ETM interfaces, was concluded that the studied factors present a behavior of high associative degree.

According to Pondorfer (2019), when there are changes in the form of land use and occupation, they tend to reflect in the natural vegetation cover, originated by loss of the natural section to urbanized areas, agricultural activities, transportation infrastructures, among others.

(Dube and Nhamo, 2019) state that, changes in vegetation cover, most of the time, cause modifications in climate variables. This can affect rainy season and consequently contributes to a thermal variation imbalance. Based on the previous information, it can be stated that the natural vegetation of an area has a direct impact on their climatic conditions, inducing the region to local temperature variations and changes in rainfall levels.

Based on (Apuri et al., 2018), every change caused by the man generates direct impacts on local or even global climatic conditions, depending directly on the size of the modification that was made. The results obtained from the trend analysis shows that the anthropic action has a direct impact on NDVI, which is the cause of changes in rainfall and temperature. Associated to the trend analysis, aiming to certify the quality of the data, the statistical methods (Mann-Kendall and Correlation) were applied.

Verifying the application of MK in environmental scenario, (Sa'adi et al., 2019) used Mann-Kendall to study the spatial pattern of changes in rainfall extremes of Sarawak in a specific time interval (1980–2014), providing an elaborate view of recent trends in rainfall of Sarawak. While Sayyad et al. (2019) analyzed, on Vojvodina, north of Serbia, the annual and seasonal trends of mean, maximum, and minimum temperatures during the periods of 1949–2013 and 1979–2013 concluding that, rainfall during and post monsoon season has non-significant decreasing trend, in another hand, pre monsoon and winter season presents non-significant increasing trend.

From the correlation map (Figure 6), it is possible to observe the relationship between the NDVI, temperature and rainfall. The correlation coefficient defines the strength and direction of the linear relationship between two random variables (Kumar et al., 2019). Using as an example two of the variables applied in this article, NDVI and rainfall, was possible to define a coefficient that indicates how much these two variables correlate (directly or inversely proportional) (Santos and Toledo Filho, 2014). Correlation occurs when there is a linear association between the variables (Cook, 2005).

Based on the above-mentioned assertion, is possible to affirm that the Mann-Kendall and the Correlation statistical methods can be used to analyze environmental series without seasonality, obtaining results consistent with those generated by the trend analysis, corroborating to prove that every change in the vegetal coverage, according to its size, might cause climate changes on local, national or global level. So, confirming that deforestation on the Legal Amazon modify its rainfall and temperature.

According to (Rivero et al., 2009), deforestation in the Brazilian Amazon has as main causes: livestock, large-scale agriculture, slash and burn agriculture. The expansion of cattle ranching is the most significant.

Maintaining the current conditions of land use, changes in the study area natural landscape tend to increase, causing vegetation suppression, increase of urbanized areas and growth of agricultural activity. Thus, the plan addressed in the Northern Sustainable Development Report 2030, which aims to reduce deforestation in the Legal Amazon, will not be achieved. It is necessary to insert immediate plans, actions and public polices to control deforestation in order to reach the objectives set for the future.

5. Conclusion

The results of this research corroborate to the strand that, in the Legal Amazon, the forest has control over the climate. Changes caused by increased levels of anthropogenic action have a direct impact on vegetation, increase deforestation rates and cause variations in temperature and rainfall.

It was also observed that the non-adoption of actions to control natural vegetation removal increases deforestation, causing greater changes in NDVI levels, larger changes in hydrological cycle and thermal control.

Aiming to mitigating the effects caused by anthropic action in the Legal Amazon, the adoption of public policies emerges as a necessary requirement. The increase in inspection by the government, as well as the control of agricultural expansion through the Soy Moratorium, an agreement implemented in 2006 and renewed in 2016, can be highlighted as basic actions to protect the study area.

The realization of land regularization associated with existing protection legislation, such as the Action Plan for Prevention and Control of Deforestation in the Legal Amazon - PPCDAM and the Sustainable Amazon Plan - PAS, allow better management of the area, contributing to reduce the effects of deforestation in the local climate.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

The authors declare no conflict of interest.

Acknowledgements

This work was carried out with the support of CAPES - Financing Code 001

References

Alves, F.R.J., 2018a. O DESMATAMENTO DA AMAZÔNIA E SEUS EFEITOS CLIMÁTICOS. GEOgraphia.

Alves, F.R.J., 2018b. O Desmatamento da Amazônia e seus efeitos Climáticos. GEOgraphia 20, 159–162.

Andreola Serraglio, D., Sivini Ferreira, H., Levi Maganhati Mendes, R., 2019. A Atuação do Poder Judiciário Brasileiro nos Biomas Amazônia e Cerrado Visando Combater o Aquecimento Global. Rev. da Fac. Direito da UFG 42, 11–47. https://doi.org/10.5216/rfd.v42i2.50506

Apuri, I., Peprah, K., Achana, G.T.W., 2018. Climate change adaptation through agroforestry:

The case of Kassena Nankana West District, Ghana. Environ. Dev. 28, 32–41. https://doi.org/10.1016/j.envdev.2018.09.002

Barbosa, H.A., Lakshmi Kumar, T.V., 2016. Influence of rainfall variability on the vegetation dynamics over Northeastern Brazil. J. Arid Environ. 124, 377–387. https://doi.org/10.1016/J.JARIDENV.2015.08.015

Buckeridge, Ma., Ribeiro, W.C., 2018. Livro branco da água. A crise hídrica na Região Metropolitana de São Paulo em 2013 -2015: Origens, impactos e soluções, First. ed. Instituto de Estudos Avançados, São Paulo.

Cook, R.J., 2005. Encyclopedia of Biostatistics. John Wiley & Sons, Ltd, Chichester, UK. https://doi.org/10.1002/0470011815

Copertino, M., Piedade, M.T.F., Vieira, I.C.G., Bustamante, M., 2019. Desmatamento, fogo e clima estão intimamente conectados na Amazônia. Cienc. Cult. 71, 04–05. https://doi.org/10.21800/2317-66602019000400002

De Oliveira Mota, N.F., Watanabe, M.T.C., Zappi, D.C., Hiura, A.L., Pallos, J., Viveros, R.S., Giulietti, A.M., Viana, P.L., 2018. Amazon canga: The unique vegetation of Carajás revealed by the list of seed plants. Rodriguesia 69, 1435–1488. https://doi.org/10.1590/2175-7860201869336

Dube, K., Nhamo, G., 2019. Climate change and the aviation sector: A focus on the Victoria Falls tourism route. Environ. Dev. 29, 5–15. https://doi.org/10.1016/j.envdev.2018.12.006

Farias, M.H.C.S., Beltrão, N.E.S., Cordeiro, Y.E.M., Santos, C.A. dos, 2018. Impact of Rural Sttlements on the Deforestation of the Amazon. Mercator 17, 1–20. https://doi.org/10.4215/rm2018.e17009

Fearnside, P.M., 2008. Mudanças climáticas globais e a floresta amazônica. Biol. e Mudanças Climáticas Globais no Bras. 131–150.

Felfili, J.M., Silva-Junior, M.C. da, Nogueira, P.E., 1998. Levantamento da vegetação arbrórea na região de Nova Xavantina, MT. Bol. do Herb. Ezechias Paulo Heringer 3, 63–81.

Ferreira, M.D.P., Coelho, A.B., 2015. Desmatamento Recente nos Estados da Amazônia Legal: uma análise da contribuição dos preços agrícolas e das políticas governamentais. Rev. Econ. e Sociol. Rural 53, 91–108. https://doi.org/10.1590/1234-56781806-9479005301005

Filho, A.C., Souza, O.B. de, 2009. Atlas de pressões e ameaças às terras indígenas na Amazônia brasileira. Instituto Socioambiental, São Paulo.

Fisch, G., Marengo, J.A., Nobre, C.A., 1998. Uma revisão geral sobre o clima da Amazônia. Acta Amaz. 2, 101–126.

Florenzano, T.G., 1996. Dados Multisensores para Mapeamento Geomorfológico de regiões da Amazônia, in: Simpósio Brasileiro de Sensoriamento Remoto (SBSR). INPE, Salvador, pp. 629–630.

Gašparović, I., Gašparović, M., Medak, D., 2018. Determining and analysing solar irradiation based on freely available data: A case study from Croatia. Environ. Dev. 26, 55–67. https://doi.org/10.1016/j.envdev.2018.04.001

Güçlü, Y.S., 2018. Multiple Şen-innovative trend analyses and partial Mann-Kendall test. J. Hydrol. 566, 685–704. https://doi.org/10.1016/j.jhydrol.2018.09.034

Higuchi, M., Higuchi, N., 2012. A floresta Amazonica e suas multiplas dimensões: Uma proposta de educação ambiental, 2ª Edição. ed. INPA, Manaus.

IBGE, 2015. IBGE :: Instituto Brasileiro de Geografia e Estatística [WWW Document]. URL https://ww2.ibge.gov.br/home/geociencias/geografia/mapas_doc3.shtm (accessed 6.12.19).

IPAM, 2017. Desmatamento zero na Amazônia: como e por que chegar lá.

Kingo, A., Homma, O., 2015. Revista Terceira Margem Amazônia. Terceira Margem Amaz. 1, 16.

Kumar, N., Tischbein, B., Beg, M.K., 2019. Multiple trend analysis of rainfall and temperature for a monsoon-dominated catchment in India. Meteorol. Atmos. Phys. 131, 1019–1033. https://doi.org/10.1007/s00703-018-0617-2

Liesenfeld, M.V.A., Vieira, G., Miranda, I.P. de A., 2017. Ecologia do fogo e o impacto na vegetação da Amazônia. Pesqui. Florest. Bras. 36, 505. https://doi.org/10.4336/2016.pfb.36.88.1222

Lopes, J.R.F., Silva, D.F., 2013. Aplicação Do Teste De Mann-Kendall Para Análise De Tendência Pluviométrica No Estado Do Ceará. Rev. Geogr. 30, 192–208.

Malhi, Y., Roberts, J.T., Betts, R.A., Killeen, T.J., Li, W., Nobre, C.A., 2008. Climate Change, Deforestation, and the Fate of the Amazon. Science (80-.). 319, 169–172. https://doi.org/10.1126/science.1146961

Mann, H.B., 1945. Nonparametric Tests Against Trend. Econom. Soc. 13, 245–259.

Mello, N.G.R. de, Artaxo, P., 2017. Evolução do Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal. Rev. do Inst. Estud. Bras. 108. https://doi.org/10.11606/issn.2316-901x.v0i66p108-129

Molion, L.C.B., 1987. Climatologia dinâmica da Regiao Amazônica: mecanismos de precipitaçao. Rev. Bras. Meteorol. 2, 107–117.

Neeti, N., Eastman, J.R., 2011. A Contextual Mann-Kendall Approach for the Assessment of Trend Significance in Image Time Series. Trans. GIS 15, 599–611. https://doi.org/10.1111/j.1467-9671.2011.01280.x

Nóbrega, R.S., 2014. Impactos do desmatamento e de mudanças climáticas nos recursos hídricos na Amazônia ocidental utilizando o modelo SLURP. Rev. Bras. Meteorol. 29, 111–120. https://doi.org/10.1590/0102-778620130024

Office, 2016. Previsão (Função PREVISÃO) - Suporte do Office [WWW Document]. URL https://support.office.com/pt-br/article/previsÃo-função-previsÃo-50ca49c9-7b40-4892-94e4-7ad38bbeda99 (accessed 6.10.19).

Pellegrini, F.R., Fogliatto, F.S., 2001. Passos para implantação de sistemas de previsão de demanda: técnicas e estudo de caso. Production 11, 43–64. https://doi.org/10.1590/S0103-65132001000100004

Pondorfer, A., 2019. The perception of climate change: Comparative evidence from the small-island societies of Bougainville and Palawan. Environ. Dev. 30, 21–34. https://doi.org/10.1016/j.envdev.2019.04.002

Rivero, S., Almeida, O., Ávila, S., Oliveira, W., 2009. Pecuária e desmatamento: uma análise das principais causas diretas do desmatamento na Amazônia. Belo Horizonte.

Rocha, V.M., Correia, F.W.S., Gomes, W.B., 2019. Avaliação dos Impactos da Mudança do Clima na Precipitação da Amazônia Utilizando o Modelo RCP 8.5 Eta-HadGEM2-ES. Rev. Bras. Geogr. Física 12, 2051–2065.

Rocha, V.M., Correia, F.W.S., Silva, P.R.T. da, Gomes, W.B., Vergasta, L.A., Moura, R.G. de, Trindade, M. da S.P., Pedrosa, A.L., Silva, J.J.S. da, 2017. Reciclagem de Precipitação na Bacia Amazônica: O Papel do Transporte de Umidade e da Evapotranspiração da Superfície. Rev. Bras. Meteorol. 32, 387–398. https://doi.org/10.1590/0102-77863230006

Sa'adi, Z., Shahid, S., Ismail, T., Chung, E.S., Wang, X.J., 2019. Trends analysis of rainfall and rainfall extremes in Sarawak, Malaysia using modified Mann–Kendall test. Meteorol. Atmos. Phys. 131, 263–277. https://doi.org/10.1007/s00703-017-0564-3

Salati, E., Ribeiro, M. de N.G., 1979. Floresta e clima. Acta Amaz. 9, 15–22. https://doi.org/10.1590/1809-43921979094s015

Sales, A., Resende Silva, A., Alberto Costa Veloso, C., Jorge Maklouf Carvalho, E., Maia Miranda, B., 2018. Carbono Orgânico E Atributos Físicos Do Solo Sob Manejo Agropecuário Sustentável Na Amazônia Legal. Colloq. Agrar. 14, 01–15. https://doi.org/10.5747/ca.2018.v14.n1.a185

Salviano, M.F., Groppo, J.D., Pellegrino, G.Q., 2016. Análise de Tendências em Dados de Precipitação e Temperatura no Brasil. Rev. Bras. Meteorol. 31, 64–73. https://doi.org/10.1590/0102-778620150003

Santos, D. dos, Toledo Filho, M. da R., 2014. Estudo sobre a influência de variáveis meteorológicas em internações hospitalares em Maceió-AL, durante o período 1998 a 2006. Rev. Bras. Meteorol. 29, 457–467. https://doi.org/10.1590/0102-778620110324

Santos, M.R. da S., Vitorino, M.I., Pimentel, M.A. da S., 2017. Vulnerabilidade e mudanças climáticas: análise socioambiental em uma mesorregião da Amazônia. Ambient. e Agua - An Interdiscip. J. Appl. Sci. 12, 842. https://doi.org/10.4136/ambi-agua.2017

Sayyad, R.S., Dakhore, K.K., Phad, S. V, 2019. Analysis of rainfall trend of Parbhani , Maharshtra using Mann – Kendall test. J. Agrometeorol. 21, 239–240.

Veloso, M.E. da C., Araújo, E.C.E., Silva, P.H.S. da, 2010. Recuperação de Áreas Degradadas em Gilbués - PI. Teresina - PI.

Viera, A.J., Garrett, J.M., 2005. Understanding Interobserver Agreement: The Kappa Statistic 360–363.

Yue, S., Pilon, P., Cavadias, G., 2002. Power of the Mann Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series.

Zhang, W., Yan, Y., Zheng, J., Li, L., Dong, X., Cai, H., 2009. Temporal and spatial variability of annual extreme water level in the Pearl River Delta region, China. Glob. Planet. Change 69, 35–47. https://doi.org/10.1016/j.gloplacha.2009.07.003

Chapter 2 - The vulnerability of the Amazon biome: how anthropic actions contributes to climate change over time based on PCA and STA analysis.

1. Introduction

Amazon rainforest represents the biggest tropical forest on Earth, covering an area of approximately 6.5 million km^2, corresponding to 56% of the Earth's tropical forests, and bordering 9 countries, being Brazil responsible for 50% of the Amazonia total area (Barlow et al., 2011; Rosa et al., 2013; Farias et al., 2018). The forest hosts around a quarter of the terraneous species in the world and accounts for approximately 15% of the total terrestrial photosynthesis (Dirzo & Raven, 2003; Farias et al., 2018).

This are plays a very important row to global climate scenario, since it is responsible for a great amount of energy, mass and humidity exchange between the continent and the atmosphere, providing key environmental services (Rocha et al., 2019). Amazon rainforest is a great source of heat to global atmosphere, presenting a high level of evapotranspiration and latent heat liberation, influencing directly on air masses circulation in local and global scale (Satyamurty et al., 2013). In addition, this area holds around 20% of the world's water resources, directly influencing on Earth's climatic balance (Copertino et al., 2019) and has a direct influence on the rainfall regime throughout South America region, and an important part of the Western, contributing to global climate stabilization (IPAM, 2019).

In the last years, several authors studied about changes on Amazon landscape and the impacts caused by them. Prates e Bacha (2011), concluded that the productivity active expansion increases deforestation rates, causing changes on the land scape and modifying forest natural conditions, therefore, contributing to climate change. Farias et al. (2018), verified that the insertion of rural settlements, aiming to provide housing and sustainable production to families who cannot afford to acquire property, increase deforestation indices and modify atmosphere composition above Amazonia rainforest. In another study, Amaral e Silva et al. (2020), identified that the forest removal (deforestation), caused by anthropic actions, impacts on temperature and rainfall natural conditions, reflection on changes on climate conditions, presenting impacts at local, national and global scenarios.

Among the existent ways to study and analyze Amazon biome behavior, Geographic Information Systems (GIS) stands out enabling temporal and spatial study of changes in natural landscape conditions helping on areas management (Gasparovic et al., 2018). GIS allows spatial information aggregation on maps, as well as processing, analyzing and relating data that contribute, for example, to study climatic and environmental variables behavior (Amaral e Silva et al. 2020).

Idrisi software, developed by Clark Labs, is a GIS tool that allows image studies with aid of the modules provided. In this research was applies the module Earth Trends Modeler (ETM) and the interfaces Seasonal Trend Analysis (STA) and Principal Components Analysis (PCA). ETM construes trends and dynamic characteristics of time series providing a critically important resource for understanding the dynamics and evolution of environmental phenomena (TerrSet, 2020). STA performs a time series seasonal trend analysis calculating trends in seasonal parameters by modeling each year's seasonal curve and analyzing trends in the mean annual parameter (TerrSet, 2020).

Novillo et al. (2019), used ETM to study the normalized difference vegetation index (NDVI) aiming to identify the existence of differences, by land cover class and phytoclimatic type, in mainland Spain and the Balearic Islands. Amaral e Silva et al. (2020), applied ETM module, using STA interface, to analyze two climatic variables (rainfall and temperature) and an environmental variable (NDVI) looking for relate them and understand how they behave in an associated way.

On another hand, PCA divide the time series in components, searching for recurrent patterns of variability, enabling to understand the behavior of each component in relation to the studied variables (Lever et al., 2017). Ehrendorfer (1986), one of the first studies to apply PCA as a way to study environmental scenarios, investigated the possibility of identifying homogeneous precipitation areas in Austria. Zhang et al. (2017), in a most recent work, used Principal Component Analysis, associated to annual season trend analysis, to identify karst rocky desertification in southwestern China.

In this context, as can be seen, Earth Trends Modeler is widely used and can be applied in different study fields. Thereby, this study aims to use those two interfaces (STA and PCA) to analyze climatic and environmental variables (temperature, rainfall, atmospheric pressure, evapotranspiration and NDVI) behavior, associating this behavior to the natural landscape situation, allowing to understand how the environment influences climatic conditions. So, it will be possible to have knowledge about how anthropic activities modifies the natural resilience conditions, by increasing deforestation, worsening climate change situation.

2. Methodology

To achieve the objective of this study, methodology was divides into steps, as can be seeing on figure 1.

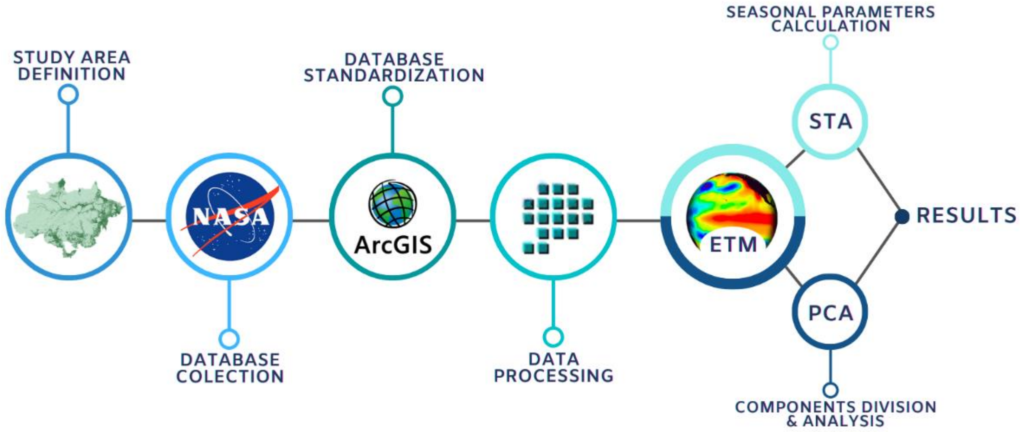

Figure 1. Methodology flowchart summary.

2.1 Study area definition

In a previously study, Amaral e Silva et al. (2020) used the Legal Amazon as the study area. The author's methodology was applied in three different biomes (Amazon, Cerrado and Pantanal), analyzing three variables (Rainfall, Temperature and NDVI), being an environmental and two climatic. In this context, focusing on study the biggest and most important Brazilian biome, and aiming to complement the author's work with a more in-depth study, this research has Amazon biome as study areas (Figure 2).

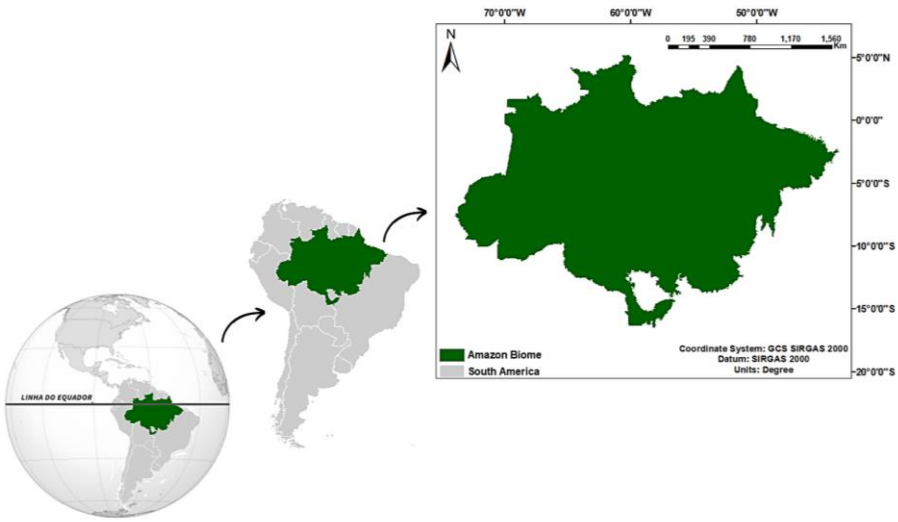

Figure 2. Study area.

Amazon is the largest Brazilian biome, covering almost half of the national territory, approximately 4.2 million km^2, present in nine states and 553 municipalities (IBGE, 2020; Rudorff et al., 2011). This area has the biggest basin in the world, covering 6 million km^2 with 1,100 affluent, being Amazon River its main river, crossing the region to flow into the Atlantic Ocean (MMA, 2020).

The study area is responsible for holding the largest terrestrial biodiversity in the planet, housing millions of animal, vegetal and micro-organisms species (Moraes, 2020). In natural landscape context, Amazon's soil generally quite sandy with a thin organic layer originates from leaves and dead animals' decomposition (FioCruz, 2020). The relief consists of plains (terrain with little variation in altitude), depressions (type of flattened relief, where low hills are found) and plateaus (terrain with elevated surface) (Florenzano, 1996; Sales et al., 2018).

Amazon is located in the equatorial region and has a hot and humid climate, result of several factors combination, being the most important one the availability of solar energy through energy balance (Fisch, 2020). The study area has an average temperature around 25 ºC with low variation over seasons and average rainfall of approximately 2300 mm/year, where evapotranspiration, on Amazon basin itself, is responsible for about 50% of total precipitation (Rocha et al., 2019).

Amazon characteristics classify it as the most important tropical forest in the world. This area has a great impact on planet's climatic conditions, since it plays a very important row in water availability and atmospheric temperature control (Merengo and Souza Jr, 2018). In addition, the humidity generated by the forest is an important source of humidity for the Center, Southeast and South of Brazil, as well as for the north of Argentina, contributing to the precipitation regime in these regions (Rocha et al., 2019).

2.2 Data base collection, standardization and processing

Database was acquired from the National Aeronautics and Space Administration - NASA open data access online portal (Table 1).

Table 1. Database source and characteristics.

Data	Description	Frequency	Period	Resolution	Source
Atmospheric Pressure	Air column lying directly above the Earth's surface.	Monthly	1981 - 2019	0.25º	NASA*
Rainfall	Amount of rain that falls on earth surface per unit area per unit of time.				
Evapotranspiration	Sum of evaporation and plant transpiration.				
Temperature	A measurement of the atmospheric kinetic energy				

NDVI	Calculated from the visible and near-infrared light reflected by vegetation.	0.05º

* https://disc.gsfc.nasa.gov/datasets?keywords=GLDAS

National Aeronautics and Space Administration makes available climatic database since 1948 through 2020, however the environmental data (NDVI) stated its measurement in 1981, what limit the study to use the whole at hand period of the other variables. Another important point adopted in this study was to work with complete time series, covering the whole measured years. In this sense, the studied period began on 1981 and finished on 2019, the last year with complete database.

Data collection was followed by database standardization in ArcGis software, developed by ESRI. In this step, data base resolution was adjusted and a coordinate system was defined. The climatic variables present a lower resolution, what makes it faster to process, so they were used as mask to NDVI standardization. Another reason to work with lower resolution is associated to the amount of information, when transferred from a higher resolution to a lower resolution, data does not lose existing information, it just generalizes (Pereira et al., 2018). When generalized, each pixel is assigned to the class with the highest probability of adequacy (Pertille et al., 2018). Referent to coordinate system, it was adopted the South America Albers Equal Area Conic. This reference system presents a low deformation level (Lumban-Gaol et al., 2019), making it possible to minimize errors in the processing step.

The last step consisted in database processing, where the module Earth Trends Modeler, available in IDRISI Selva software, developed by Clark Labs, were used. From this module, two interfaces, Seasonal Trend Analysis (STA) and Principal Components Analysis (PCA), were applied. Processing was carried out as shown in figure 3.

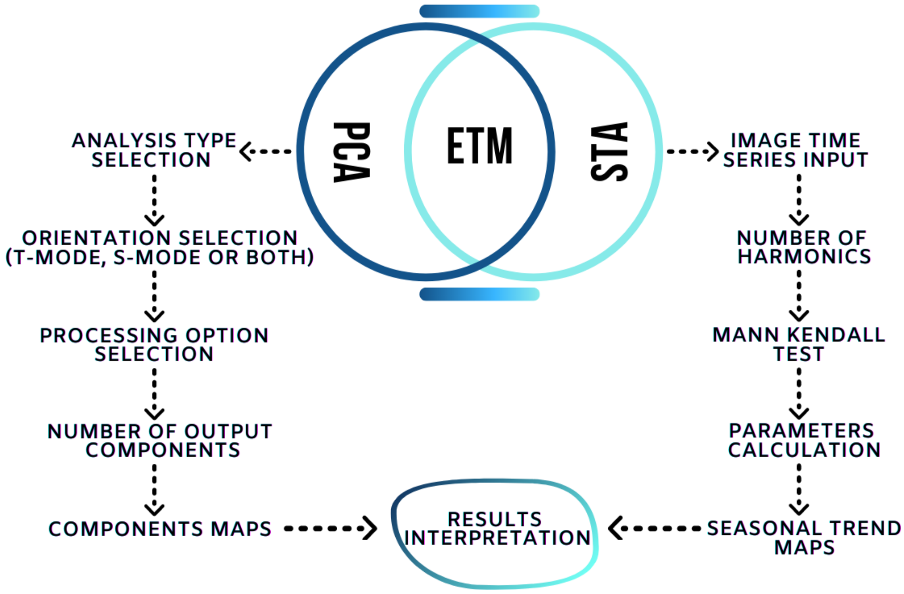

Figure 3. Summarized processing flowchart.

2.3 Principal Components Analysis (PCA)

According to Lever, Krzywinski and Altman (2017), PCA minimizes data by geometrically projecting these into lower dimensions called principal components (PCs), in order to find the best data summary using a limited number of PCs. The first PC is chosen to minimize the total distance between the data and its projection. By minimizing this distance, the projected points variance is maximized. The second component is selected in a similar way, with the additional requirement of not being correlated with the previous component. For example, the projection on PC1 is not correlated with the projection on PC2. The PC selection process has the effect of maximizing the correlation between the data and its projection and is equivalent to performing multiple linear regression on the projected data in relation to each variable of the original data (Altman and Krzywinski, 2015).

However, PCA also has limitations that must be considered when interpreting the results obtained, for example, the underlying data structure must be linear; patterns that are highly correlated may not be identified, since all PCs are not correlated. As with all statistical methods, the PCA can be misused (Lever et al, 2017). The scale of variables can cause different results of PCA and it is very important that the scale is not adjusted to match previous data knowledge. PCA is a tool to identify the main axes of variation within a data set and allows easy exploration of these data seeking to understand the key variables in the data and to identify outliers. Applied correctly, it is one of the most powerful tools in the data analysis toolkit (Lever et al, 2017).

In this research, PCA was applied in order to identify the variables that have the greatest influence on climatic conditions in the Amazon biome. In the PCA algorithm, the number of principal components is determined based on a rule proposed by Kaiser (1960). According to this rule, a component will be retained if its eigenvalue is greater than the unit (Uddin *et al*, 2019). In this context, the first four components of each variable were studied.

2.4 Seasonal Trend Analysis (STA)

There is currently a substantial interest in identifying seasonal patterns as a means of obtaining answers about the Earth system and global changes (Sparks and Menzel, 2002;

Novillo et al, 2019). These changes in seasonality have important implications for resident and migratory species in a given region (Dunn 2010). Due to the high temporal frequency and coverage area, time series of Earth observation satellite images hold significant promise in monitoring seasonal cycles (Studer et al, 2007; Bunn and Goetz, 2006). However, in practice, studying seasonal trends can be challenging due to noise, such as the presence of clouds, high frequency variability, such as the Madden-Julian oscillation and short-term interannual events, such as El Niño/Oscillation of the South (ENSO). In this context, Seasonal Trend Analysis (STA) appears as a tool that allows the study of time series in a faster and more accurate way (TerssSet, 2020).

STA performs a seasonal trend analysis of images from a time series, for example, calculating trends in seasonal parameters, such as phenological changes by modeling the seasonal curve for each year and analyzing trends in the average annual parameter, the seasonal parameters and the event timing. The analysis performs a harmonic regression of images followed by a Kendall analysis of the amplitude and phases of each year generated by the harmonic regression (TerrSet, 2020).

This work used this model to analyze the time series variations of NDVI, rainfall, surface pressure, evapotranspiration, surface temperature and atmospheric temperature data, to understand and monitor the databases behavior for later comparison. The period from 1981 to 2019 was selected because it presented better data interpolation, allowing higher quality results. Mann Kendall (MK) test was performed. This analysis is a robust, sequential and nonparametric method applied to determine whether a specific data series has a statistically significant trend within a given time series (Mann, 1945). This method is suggested by the World Meteorological Organization (WMO) to assess the trend in time series of environmental data (Lopes and Silva, 2013).

According to Güçlü (2018), the Mann-Kendall test is applied in time series without seasonality and performed individually on each pixel. This test ranges from -1 to 1, with the negative extreme indicating a decrease, the positive extreme indicating an increase and 0 indicates a balance between losses and gains in the variable (Sayyad et al., 2019).

3. Results

Regarding the principal component analysis, the components were selected when the eigenvalue value is greater than a unit, as determined by the Kaiser rule (1990). In this context, 3 components of each variable were studied.

The values related to each of the components referring to the studied variables can be seen in Table 1.

Table 1 – Component’s eigenvalue related to each variable studied

Variable studied	Component 1*	Component 2*	Component 3*
Atmospheric temperature	55.50	11.61	8.77
Surface temperature	63.49	11.53	6.21
Surface pressure	90.24	9.16	0.24

NDVI	54.60	9.51	4.31
Rainfall	40.16	21.80	12.23
Evapotranspiration	25.43	21.68	16.69

* The values assigned to each component are dimensionless, since these are values that demonstrate the explanatory capacity of the components.

For the six variables studied, the principal components analysis showed better quality for pluviometry, NDVI, surface temperature, atmospheric temperature and evapotranspiration. In the surface pressure case, components 3 obtained values less than a unit, making the data less accurate and difficult to interpret.

Following data processing, maps for the components of each variable were obtained. It should be noted that the interpretation of the factors that interfere in each component is individually related to each variable, so, although the component is the same, it does not mean that the interfering factor is equal to all variables.

Figures 4, 5, and 6 represent the three components covered in this study. Components 3 of the variable “Surface pressure” were inserted to maintain the research standard of comparison, as well as to demonstrate the difficulty of interpretation due to data inaccuracy.

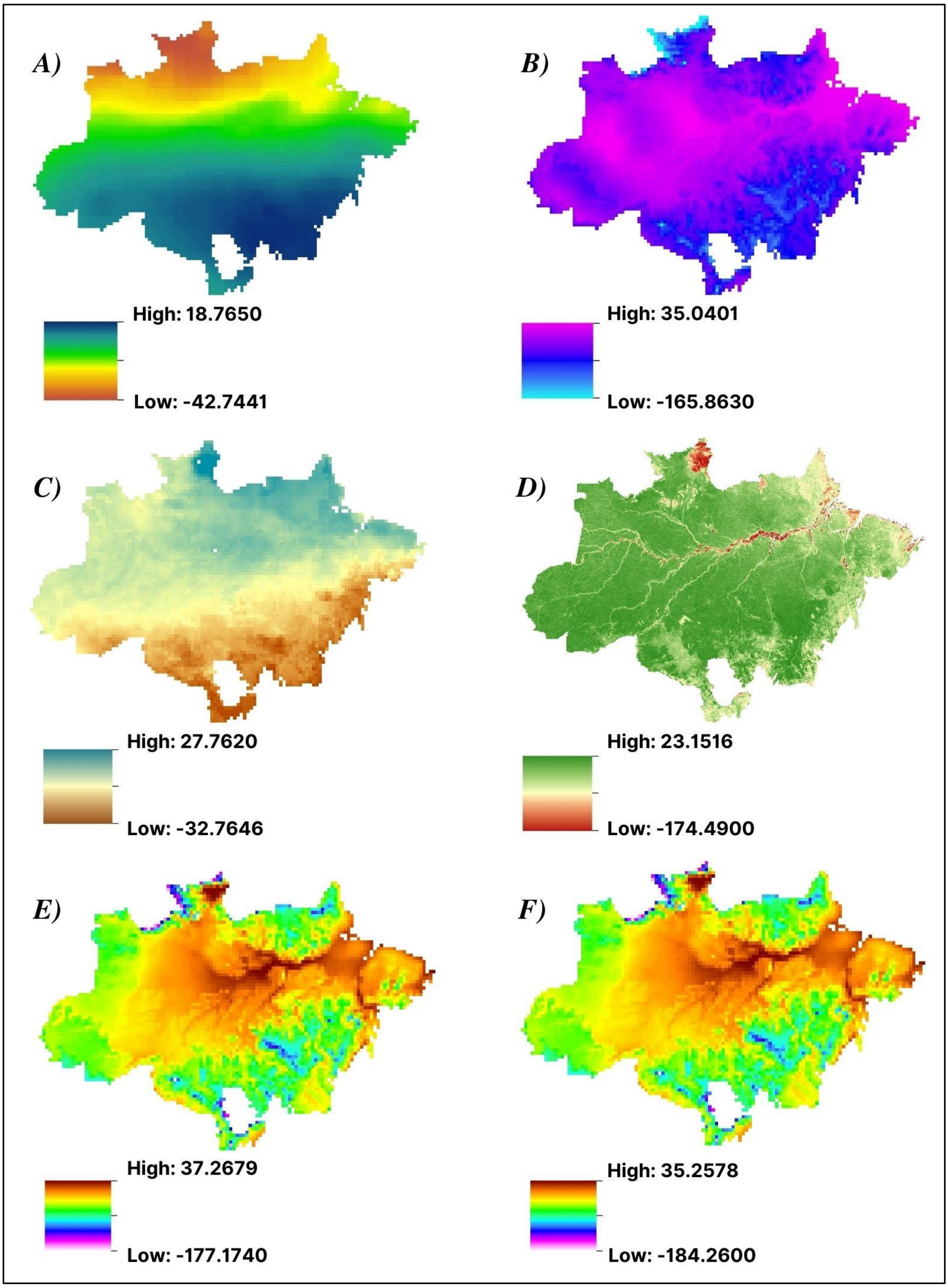

Figure 4. Demonstrative maps of component 1. a) Rainfall; b) Surface pressure; c) Evapotranspiration; d) Normalized Difference Vegetation Index - NDVI; e) Atmospheric temperature; f) Surface temperature.

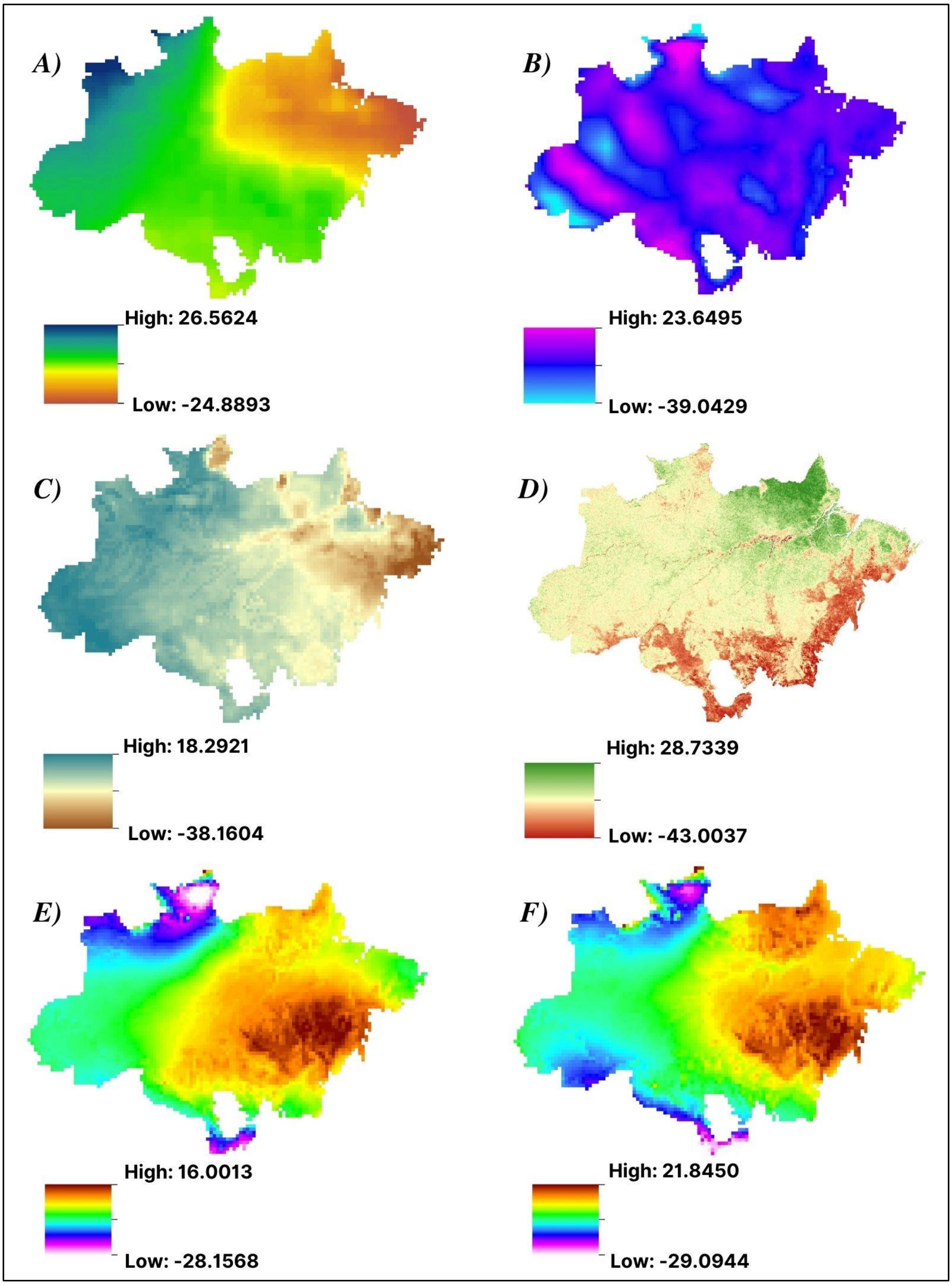

Figure 5. Demonstrative maps of component 2. a) Rainfall; b) Surface pressure; c) Evapotranspiration; d) Normalized Difference Vegetation Index - NDVI; e) Atmospheric temperature; f) Surface temperature.

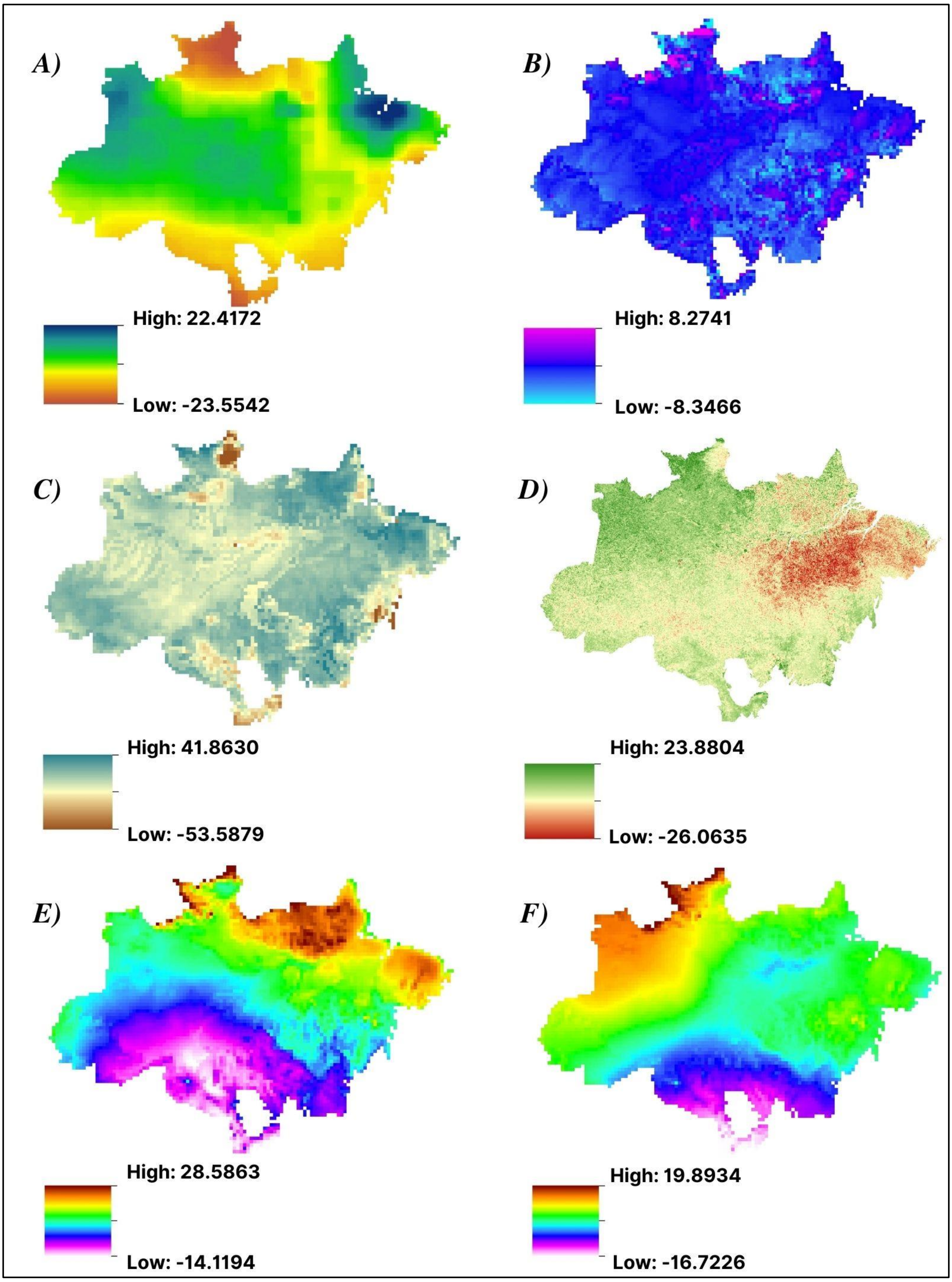

Figure 6. Demonstrative maps of component 3. a) Rainfall; b) Surface pressure; c) Evapotranspiration; d) Normalized Difference Vegetation Index - NDVI; e) Atmospheric temperature; f) Surface temperature.

From the analysis of the researched data, and based on the studies of other authors (Zhang et al., 2017; Abiodun et al. 2017; Sun & Sun, 2017), it was possible to identify that, among the factors that cause interference in the studied variables, the effects of latitude, anthropic actions, relief and maritimity are the ones that most cause changes in the components behavior, which does not eliminate the effects of the other existing factors in the study area.

In the context of the results obtained through Seasonal Trend Analysis model, as previously mentioned, the Mann Kendall test was applied to this interface. Figure 7 shows the data obtained within the scale used (-1 to 1).

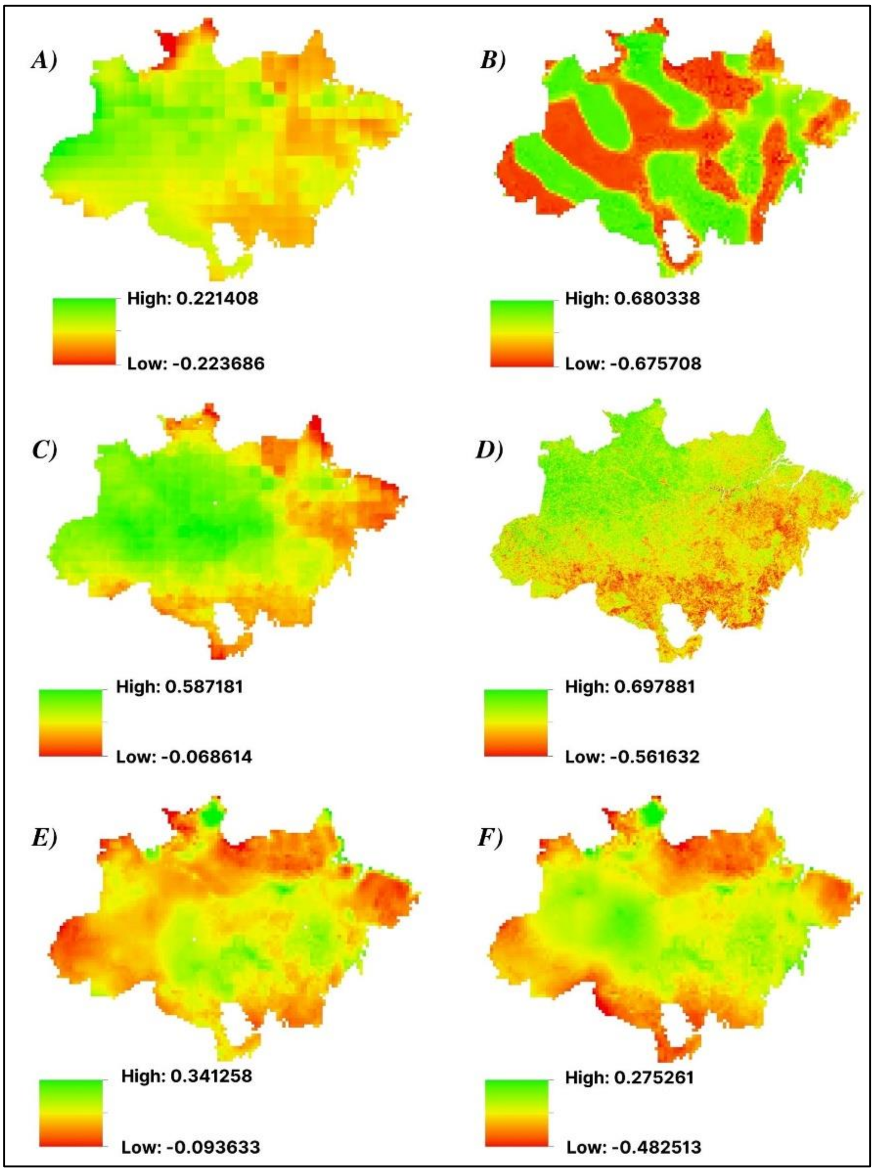

Figure 7. Mann Kendall test. a) Rainfall; b) Surface pressure; c) Evapotranspiration; d) Normalized Difference Vegetation Index - NDVI; e) Surface temperature; f) Atmospheric temperature.

It is worth to mention that among all the variables studied, “Surface Pressure” (Figure 7b) showed an unusual behavior what can be caused by data inaccuracy as occurred in PCA analysis. However, this variable still interfering in the forest behavior, being important to this research.

In addition to the MK test, the study of the time series behavior of each variable, for the entire study area, was carried out. It was possible to observe the variation within each of the variables, helping to identify their behavioral tendency. Table 2 shows the monthly averages of the coefficients obtained for each variable.

Table 2 - Monthly average of the coefficients obtained for each variable

	NDVI		Rainfall		Surface temperature	
MONTH	1981	2019	1981	2019	1981	2019
JAN	0.743	0.785	259.20	311.04	29.94	29.99
FEV	0.725	0.745	317.52	356.40	29.93	29.98
MAR	0.710	0.723	324.00	356.40	29.95	29.99
APR	0.715	0.763	265.68	298.08	29.95	29.98
MAY	0.745	0.845	168.48	194.40	29.92	29.95
JUN	0.783	0.923	71.28	90.72	29.88	29.92
JUL	0.800	0.938	25.92	32.40	29.86	29.94
AUG	0.788	0.900	45.36	45.36	29.89	30.02
SEP	0.760	0.840	90.72	90.72	29.95	30.11
OCT	0.740	0.810	136.08	142.56	30.00	30.15
NOV	0.740	0.810	168.48	194.40	30.01	30.12
DEC	0.740	0.820	181.44	233.28	29.99	30.07
	Atmospheric temperature		Evapotranspiration		Surface pressure	
MONTH	1981	2019	1981	2019	1981	2019
JAN	29.93	29.83	101.09	147.74	99347.50	99284.50
FEV	29.92	29.82	103.68	138.67	99346.75	99333.00
MAR	29.94	29.83	101.09	119.23	99321.00	99353.25
APR	29.95	29.83	92.02	100.44	99325.25	99386.50
MAY	29.93	29.80	84.24	93.96	99391.25	99462.50
JUN	29.89	29.81	84.24	104.98	99488.00	99551.75
JUL	29.88	29.88	90.72	119.88	99542.50	99583.50
AUG	29.91	30.00	97.20	130.25	99506.50	99511.00
SEP	29.97	30.09	97.85	130.90	99403.75	99362.25
OCT	30.01	30.10	94.61	129.60	99308.00	99224.50
NOV	30.01	30.02	93.31	134.14	99278.75	99172.50
DEC	29.99	29.94	93.31	139.97	99293.00	99187.00

Figure 8. illustrates the behavior of the variables based on the graphics obtained after processing.

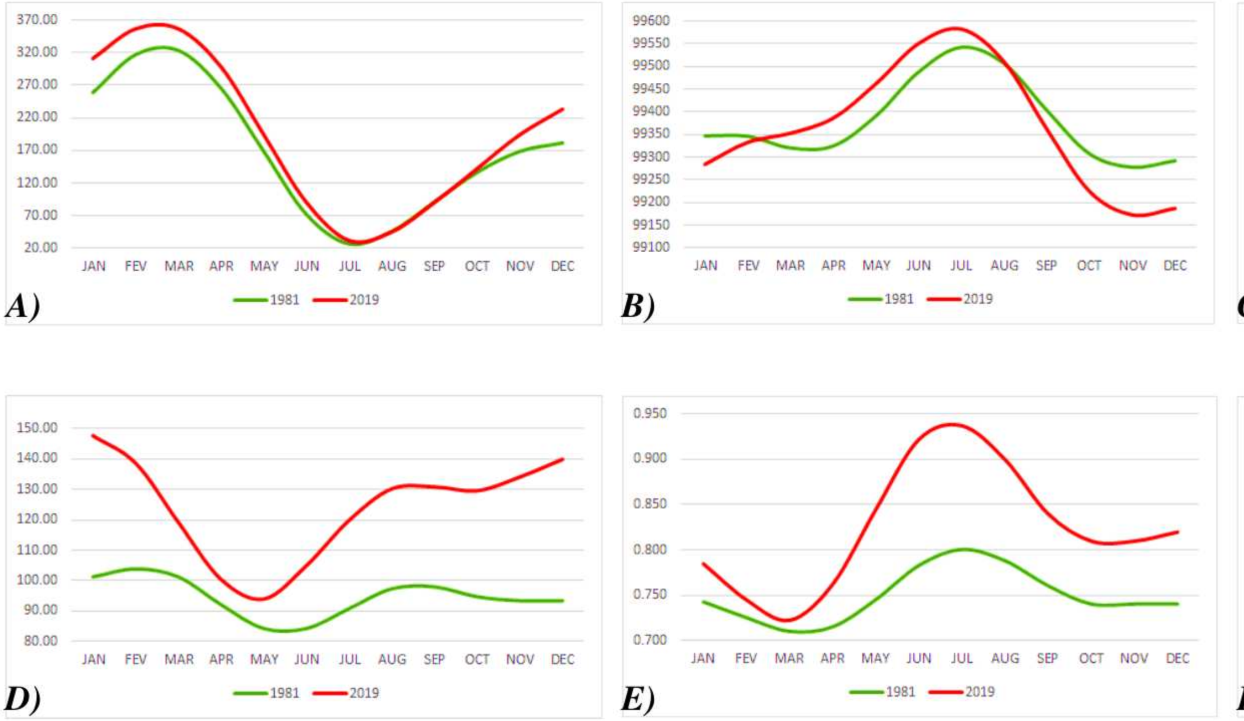

Figure 8. Time series behavior of the variables studied in STA. a) Rainfall; b) Surface pressure; c) Surface temperature; d) Evapotranspiration; e) Normalized Difference Vegetation Index - NDVI; f) Atmospheric temperature.

Crossing the obtained data, it was possible to verify that the variables “Rainfall” and “Evapotranspiration” showed a tendency to decrease over time. On the other hand, the other variables showed an upward trend.

4. Discussion

In this research, as a way to optimize the discussion regarding the results obtained, this topic was divided into two subtopics: “Principal Components Analysis” and “Seasonal Trend Analysis”. Thus, allowing a better understanding of how the studied variables are affected and how they interrelate.

4.1 Principal Components Analysis

Before discussing about the components, it is worth noting that the interpretation of the components, regarding the variation of existing values in the analysis, is not related to the intensity of the variable variation, but rather as to their behavioral characteristic. The variation of the color spectrum is linked to the different behaviors of the studied variables, not indicating whether they vary more or less.

For component one (Figure 4), among all the factors presents that modify the variables behavior, it was possible to identify that “Rainfall” and “Evapotranspiration” are most altered by latitudinal variation. In general, areas close to the Equator show greater rainfall than other areas, such as the poles and temperate regions. This occurs due to the greater evaporation provided by the higher incidence of sunlight in the equatorial region. Regardless of the season, the equatorial zones receive more heat from the sun. This establishes the following relationship between climate and latitudes: the lower the latitude, the higher the temperatures (Pena, 2021).

According to Khan and Ul Hasan (2017), temperature interferes directly on evapotranspiration elevating its rate according to the increase of the heat. On the other hand, high rates of evapotranspiration impact on rainfall, raising this variable (Hanif et al, 2013). The Equator represents the hottest zone, where temperature reach high values. In this area, evapotranspiration tends to increase, because of the heat, and with that, rainfall follows the same trend (Allen, et al., 2016). That explains the behavior of this variables (Rainfall and Evapotranspiration) in component 1.

Regarding “Surface pressure”, “Atmospheric temperature” and “Surface temperature” variables, for component 1, relief is the factor that presents most interference. Relative to relief, pressure and temperature presents a similar behavior, where those variables are inversely proportional to the relief. There is an important relationship between temperature, surface pressure and altitude, the higher the altitude, the lower the temperature and the lower the pressure (Moreira and Silva, 2017). Surface pressure tends to be higher in the lower regions, thanks to the effects of gravity. In this way, with higher pressure, more concentrated in the air are the molecules, favoring the increase in temperatures (Pena, 2021). Gravity moves the air to lower areas, making the air from higher places rarer and consequently has a lower pressure value. Low pressure causes a lower concentration of water vapor and, consequently, a decrease in the ability to retain heat, which makes the air temperature colder.

For NDVI, component one showed to be related to the vegetation presence. As can be seen in figure 4d, the variable presented different behavior mainly in areas that are classified as water bodies. Even though water showed the most contrast, it is possible to see that areas close to Pantanal and Cerrados biomes also have a different trend, where the color green fades representing another characteristic of variation. In this region is located the Deforestation Arc.

Deforestation arc covers the west and northwest of Maranhão; the east, south and part of the west of Pará; the west and north of Tocantins; the east, central-west and north of Mato Grosso, the entire state of Rondônia and Acre and the south of Amazonas (Sabino-Santos et al., 2020). In this area, most of the development and occupation policies of the territory were concentrated, driving the gradual expansion of the agricultural frontier. This arc corresponds to the territory of approximately 256 municipalities where the expansion of forest cutting has been observed more intensely. Currently, it is in this area that approximately 75% of the gross deforestation of the entire Brazilian Amazon is concentrated (IPAM, 2020). In this sense it is possible to understand that the different behavior associated to the NDVI variable in component 1 is connected to the presence of forest, where those areas that presents a lower amount has a different color spectrum.

About the effects of maritimity, it acts on component 2 for "Rainfall", "Evapotranspiration", "Surface temperature" and "Atmospheric temperature", as well as in component 3, where the variable NDVI is the one that presents its behave based on this factor (Figure 6d). For maritimity, those regions close to oceans and seas have a greater amount of rain than the regions located within the continents due to the greater amount of evaporation from ocean waters. Analyzing figures 5a and 5c, it is possible to see that the northeast region of Amazon biome, where the contrast is clearer, presents a different behavior than the rest of this area.

The distribution of rainfall in the Amazon is related to the operation dynamics of the main surface atmospheric systems in the region, namely: 1) Continental Equatorial Air Mass, with center of origin in the west of the region; 2) Intertropical Convergence Zone, formed by the convergence of trade winds; and 3) cold fronts, coming from extratropical latitudes that most frequently reach the south of the region. This biome has an important supply of moisture from the Atlantic Ocean, through the Low Level Jet (LLJ). At the highest levels of the troposphere, other systems, such as Alta de Bolivia, work together with those in the production of rain over the Amazon (França and Mendonça, 2016).

Rainfall in the Amazon region is largely influenced by conditions in the Atlantic and Pacific oceans. The South Oscillation in the Equatorial Pacific, associated with the El Niño phenomenon, allows to understand part of the interannual climate variability in the region (Marengo and Nobre, 2009). Cavalcanti and Silveira (2013) state that the warming of the Pacific (El Niño) is associated with the rainfall reduction in the northeast of the region. In the east, west and northwest of the Amazon, rainfall reduction by El Niño occurs in just a few months of the year.

Related to evapotranspiration, as said before, this variable is associated to the rainfall, that is why those two variables presents the same factor according to the components covered in this study. Due to the variations caused by the ocean, such as the displacement of the air masses due to trade winds and phenomena such as El Niño, the humidity provided by the vegetation is also affected (Martins, 2020). Although the variation in evapotranspiration is not as sudden as in the rainfall, both show the same behavior, the first one being affected by the sum of the presence of forest and maritimity, directly reflecting on pluviometric levels. In this context, the variation of NDVI in component 3 follows the same path as rainfall and evapotranspiration, been the last one direct affected by the presence of vegetation.

Maritimity interferes directly in air humidity due to the high rate of evaporation of ocean waters (Gobo et al., 2018). On the other hand, humidity causes a higher incidence of rainfall, which happens when the moisture present in the air condenses, inducing vegetation development. In this context, the difference in behavior present in figure 6d can be explained by the difference in the intensity of rain caused by the movement of air masses brought from the ocean and distributed differently within the Amazon rainforest. It is worth to remember that the difference in rain distribution is also associated to the relief.

The oceans proximity also interferes with atmospheric processes. Water, by absorbing a greater amount of heat, means that coastal cities have a lower thermal range, that is, during the year, temperatures do not vary much. The farther from the coast, the greater the thermal amplitude, because with the lowest concentration of moisture in the air, the tendency is for there to be a drier climate in the warmer months. In the winter, nights are much colder than on the coast, as there is not enough water vapor in the atmosphere to retain heat close to the surface (Santos and Moraes, 2016). In this sense, air masses formed in the oceans are characterized by their high humidity, together with relief and the vegetation presence those air masses cause different variations in temperature. Closer to the ocean the temperature does not show the same behavior observed in the innermost part of the continent.

Regarding “Surface Pressure” and “NDVI” in component 2, these variables are most affect by vegetation presence and anthropic action, respectively. Pressure variates according to the air column, as well as the presence of water molecules on the atmosphere, where a humid air mass exerts less pressure than a drier air mass (Freitas et al., 2018). For NDVI, anthropic action such as burning, deforestation, agriculture and livestock, can change the natural landscape irreversibly.

The increase in the exploitation of vegetated areas causes their degradation, causing direct impacts on local climatic conditions and, in the case of the Amazon, altering the climatic situation in the national and global scenario (Amaral e Silva et al., 2020). As can be seen in figure 5d, the regions south and southeast of Amazon biome show a different behavior when compared to the other regions. In this area deforestation rate is higher because the presence of the Deforestation Arc and due to the expansion of the agricultural frontier. Soy cultivation in Cerrado and the presence of livestock in the Pantanal biome generates the necessity to expand areas aiming on higher productions, in this sense, land management activities are applied, mainly burning and deforestation, changing the natural landscape by removing vegetation (Riveiro et al., 2009; Magalhães et al., 2019).

Anthropic actions were also the main factors for the variables “Rainfall” and “Evapotranspiration” for component 3 (Figures 6a and 6c). As studied by Amaral e Silva et al (2020), Amazon rainforest presents a high interference in the climate of the region, where modifications in the forest, as deforestation, reflects in the decrease of rain, since the forest is the main source of water by evapotranspiration. Due to the intense evapotranspiration of the forest, increased by the high temperatures, humid masses are formed in large quantities that move in the north-south orientation of the Andes Mountain Range, which works as a screen, until reaching the central-south region states. Part of these masses is also exported to the Caribbean and the Pacific Ocean, which places the Amazon Rainforest in a condition of great global importance in terms of its influence on the rainfall regime over a large territorial area in Latin America (Rios Voadores, 2016).

The Amazon rainforest works like a water pump. It pulls the moisture evaporated by the Atlantic Ocean into the continent and carried by the trade winds, forming the "Flying Rivers". Flying rivers are atmospheric water courses, formed by air masses laden with water vapor, often accompanied by clouds, and are propelled by winds. These air currents carry moisture from the Amazon Basin to the Midwest, Southeast and South of Brazil (Nascimento and Quadros, 2018).

In component 3, “Surface temperature” and “Atmospheric temperature” were most affected by latitudinal variations. Both surface and atmospheric temperature have a direct influence on latitudinal variations, especially in the regions between the tropics of Cancer and Capricorn, with their highest increases close to Ecuador (Allen et al., 2016). The Earth's surface receives variable solar energy, according to the latitude, due to the Earth's ellipsoid shape. Low latitudes (equatorial region) receive greater heat per unit area than the poles, due to the angle of the incident solar radiation. The heat received by a given area on the Earth's surface depends on the intensity and duration of the sunlight, and both factors directly depend on latitude (Medeiros et al., 2018).

In the Amazon region, the occurrence of smaller thermal amplitudes is expected, since the thermal amplitude is directly related to latitude and other factors, that is, lower latitudes represent smaller amplitudes (Leite et al., 2014). As can be seeing in figures 6e and 6f, both temperatures present latitudinal variations, but clearly there are influence of other factors. Atmospheric temperature shows a high influence of maritimity added to the variation of latitude, on the other hand, surface temperature presents a behave based on the presence of stand forest sum to the effects of latitude.

Surface pressure does not demonstrate accurate data to make it possible to perform data interpretation. As previously stated, when eigenvalue is smaller than the unit, the components tend to be inaccurate causing confusion in the result generated by the software.

4.2 Seasonal Trend Analysis

Observing the MK analysis on figure 7 it is possible to see that the variables are correlated as observed by Amaral e Silva et al. (2020). Amazon’s northwest region, as can be seen, presents tendency to increase the variables “Rainfall”, “Evapotranspiration”, “NDVI” and “Atmospheric temperature”, while “Surface temperature” decreases over time. On other hand, a different behavior can be observed in the northeast/southeast of the biome, where the variables demonstrate the reverse trend.

In the Amazon biome, precipitation recycling is one of the factors that most contribute to water cycle (Rocha et al, 2017). The concept of precipitation recycling refers to the feedback mechanism between the surface and the atmosphere where local evapotranspiration contributes, significantly, in total precipitation over the region (Fernandes et al., 2015). In this context, analyzing Figure 7a and 7c, where shows that “Evapotranspiration” and “Rainfall” presents similar behaviors, is possible to conclude that these variables are directly proportional. Increases in evapotranspiration levels contribute to greater accumulation of humidity, reflecting in the intensification of local precipitation (Motoki et al., 2020).

The behavior of “Evapotranspiration” and “Rainfall” variables, can be seen on “NDVI” and “Atmospheric temperature” (Figures 7d and 7f). Evapotranspiration influences rain through atmospheric recycling processes modifying regional patterns of temperature, air humidity and soil moisture. The Amazon rainforest acts as an indispensable source of heat for the global atmosphere through its intense evapotranspiration and release of latent heat in the middle and upper tropical troposphere, contributing to the generation and maintenance of atmospheric circulation on regional and global scales (Satyamurty et al., 2013). So, the increase of the forest in northwest region contributes to a higher level of evapotranspiration, accumulating more water vapor on the atmosphere. Water vapor is essential because it directly affects the energy balance of the Earth's atmosphere, since as water vapor increases the temperature of the atmosphere tends to rise (Freitas et al., 2018).

About “Surface temperature” it is related to thermal sensation, what means that this variable measures the average surface skin temperature (NASA, 2020). A higher evapotranspiration implies a greater energy release, not allowing the heat to be absorbed by other surfaces/bodies (trees, soil, leaves, etc.), decreasing the sensitive heat (Serrão et al., 2019). According to Amaral e Silva et al. (2020), the variation in air temperature is attributed to energy in the form of sensitive heat present in the air. So, since “Evapotranspiration” is increasing in the northwest over the period covered, sensitive heat tends do decrease, reducing surface temperature.

Regarding the Amazon’s northeast/southeast region, this part of the biome presents a reduction in “Evapotranspiration”, “NDVI” and “Rainfall”, while “Surface temperature” and “Atmospheric temperature” tend mostly to increase. Showing a different trend when compared to the northwest region.

Amazon’s northeast/southeast region suffers with the Deforestation Arc, where the intense anthropic activities, such as forest fires resulting from the expansion of agricultural frontier; selective deforestation due to logging activities; the accelerated industrialization process since the 1950s; lack of territorial ordering; monoculture of grains and introduction of exotic species, among other, changes the natural landscape causing the reduction of NDVI, since the natural forest is removed (Nepstad et al., 2008; Vieira et al., 2008; Matricardi et al., 2010; Amaral e Silva et al., 2020).

The substitution of natural cover for other areas changes, in the first instance, the thermodynamic characteristics of the surface. Vegetated areas tend to use the energy available in the environment in evapotranspiration processes, while areas of exposed and/or built soil use the available energy primarily for the flow of sensitive heat, responsible for the increase in air and surface temperature (Pavão et al., 2017).

In this context, the forest removal contributes to evapotranspiration decrease, what reflects in lower amounts of rain and higher surface and atmospheric temperatures. Evapotranspiration connects the terrestrial and atmospheric hydrological processes that can return up to 60% of all terrestrial precipitation back to the atmosphere (Juárez et al., 2008;

Seneviratne et al., 2010). About 30% to 50% of precipitation in the Amazon is due to regional evapotranspiration, especially during the summer (Rocha et al., 2015).

Aiming to present a more consistent discussion about the results disclosed in figure 8, the study was divided into two periods (rainy season and dry season). According to Freire et al. (2018), in the Amazon biome the rainy season occurs between October and April, while dry season starts on May and runs until September.

As can be seen in figure 8a, “Rainfall” presents the same behavior identified by Freire et al. (2019), presenting the same seasonality. May through September shows the lowest levels of “Rainfall”, at the same time, this period presents elevation in “Surface temperature”, “Atmospheric temperature”, “Evapotranspiration”, “Surface pressure” and “NDVI”.

In Amazon biome the dry season, mainly closer to the Deforestation Arc, is the period when occurs intensification of irrigated agriculture (Alves and Homma, 2020). In this context, landowners intensify agricultural activities, increasing the need for soil management. Among the types of soil management, fires are more frequent (Cassettari and Queiroz, 2020). In dry periods, these activities are used constantly in the agricultural sector as a way of expanding agricultural frontiers, making the risk of spreading fire a reality, inducing uncontrolled fires (Salazar Latorre et al., 2017). These fires have an impact on the regional climate and impair the functioning of ecosystems and their biodiversity. Fire use and exposed soils contributes to the increase of surface temperatures, since it elevates the amount of heat close to the surface (Lotufo et al., 2020). In this context, since the area is irrigated, with higher temperatures comes the increase of evapotranspiration, elevating the amount of water vapor on the atmosphere, what elevates the atmospheric temperature.

Regarding NDVI, even though there is higher deforestation on the northeast/southeast and lower rainfall during the dry period, the agriculture contributes to the elevation of this index, since it has a direct relationship with the biophysical characteristics of the plant (Brito et al., 2017). In this context, new cultivated areas represent a greater amount of vegetative areas, increasing NDVI.

On the other hand, during rainy season the behavior is reversed. The elevation of pluviometry causes lower temperatures, both surface and atmospheric. In addition, evapotranspiration presents tendency to decrease over time. NDVI decreases since the presence of clouds, shadows and soil reflectance compromises the measurement of this index. The reflectance of the soil is influenced by the water content, which tends to be darker when wet and also by surfaces that reflect light in different directions (Brito et al., 2017). The presence of clouds compromises the image partially or totally, causing loss of information in the image or shading the soil, interfering in obtaining the Normalized Difference Vegetation Index (Ribeiro et al., 2019).

5. Conclusion

This study allowed to conclude that there are several factor that influences Amazon’s climate. According to PCA analysis, factors such as latitude, anthropic actions, relief and maritimity are the ones that most cause changes in the Amazon rain forest, modifying the climate behavior. It was also possible to identify that those factor, added to others also active in the region, acts together potentiating the climatic changes of this biome.

STA showed the interrelationship between the studied variables, allowing to observe their seasonal behavior and the reflection of anthropogenic activities in the climatic context of the region. In this context, it was possible to conclude that the climatic variables present a natural trend that is directly modified by activities such as agriculture and pasture. So, anthropic actions induce landscape transformation, mainly by fires applied to soil management, causes impacts on regional climate, reflecting on national and global climate change over time.

References

ALLEN, J. L. et al. Interactions between rates of temperature change and acclimation affect latitudinal patterns of warming tolerance. Conservation Physiology, v. 4, n. 1, p. 1–14, 2016.

ALVES, R. N. B.; HOMMA, A. K. O. O fogo na agricultura da Amazônia. In: Embrapa Amazônia Oriental. Brasilia: Embrapa, 2020. p. 36–40.

AMARAL E SILVA, A. et al. Anthropic activities and the Legal Amazon: Estimative of impacts on forest and regional climate for 2030. Remote Sensing Applications: Society and Environment, v. 18, n. March, p. 100304, abr. 2020.

BARLOW, J. et al. Using learning networks to understand complex systems: A case study of biological, geophysical and social research in the Amazon. Biological Reviews, v. 86, n. 2, p. 457–474, 2011.

BRITO, P. V. D. S. et al. Análise comparativa da umidade da vegetação de áreas de caatinga preservada, agricultura irrigada e sequeiro. Journal of Environmental Analysis and Progress, v. 2, n. 4, p. 493–498, 2017.

Bunn, Andrew & Goetz, Scott. (2006). Trends in Satellite-Observed Circumpolar Photosynthetic Activity from 1982 to 2003: The Influence of Seasonality, Cover Type, and Vegetation Density. Earth Interactions - EARTH INTERACT. 10. 10.1175/EI190.1.

CASSETTARI, G. A.; DE QUEIROZ, T. M. BALANÇO HÍDRICO E CLASSIFICAÇÃO CLIMÁTICA NA BACIA DO RIO JAUQUARA, REGIÃO DE TRANSIÇÃO ENTRE O CERRADO E AMAZÔNIA BRASILEIRA. Revista Brasileira de Climatologia, v. 26, p. 70–88, 10 fev. 2020.

CAVALCANTI, I. F. A.; SILVEIRA, V. P. Influência das TSM dos oceanos Pacíficos e Atlântico nos eventos de seca. In: BORMA, L de S.; NOBRE, C. A. Secas na Amazônia. São Paulo: Oficina de Textos, p. 78-88, 2013.

COPERTINO, M. et al. Desmatamento, fogo e clima estão intimamente conectados na Amazônia. Ciência e Cultura, v. 71, n. 4, p. 04–05, 2019.

DIRZO, R.; RAVEN, P. H. Global state of biodiversity and loss. Annual Review of Environment and Resources, v. 28, p. 137–167, 2003.

DUNN, R. O. Other Alternative Diesel Fuels from Vegetable Oils and Animal Fats. In: The Biodiesel Handbook. [s.l.] Elsevier, 2010. p. 405–437.

Ehrendorfer, M. (1987). A regionalization of Austria's precipitation climate using principal component analysis. Journal of Climatology, 7(1), 71–89. doi:10.1002/joc.3370070107

FARIAS, M. H. C. S. et al. Impact of Rural Sttlements on the Deforestation of the Amazon. Mercator, v. 17, n. 05, p. 1–20, 15 maio 2018.

FARIAS, Monique & Beltrão, Norma & Assis, Cleber & Cordeiro, Yvens. (2018). IMPACT OF RURAL SETTLEMENTS ON THE DEFORESTATION OF THE AMAZON. Mercator. 17. 10.4215/rm2018.e17009.

FERNANDES, F. M. et al. Biodiesel no mundo e no Brasil : situação atual e cenarios futuros. 10o Congresso sobre Geração Distribuida e Energia no meio Rural, v. 10, p. 10, 2015.

FIOCRUZ. Bioma AmazôniaSão PauloFiocruz, , 2020.

FISCH, G. Clima da amazônia. Centro de Previsão de Tempo e Estudos Climáticos (CPTEC/INPE), p. 1–14, 2020.

FLORENZANO, T. G. Dados Multisensores para Mapeamento Geomorfológico de regiões da Amazônia. Simpósio Brasileiro de Sensoriamento Remoto (SBSR). Anais...Salvador: INPE, 1996

FRANCA, R. R. DA; MENDONÇA, F. DE A. A pluviosidade na Amazônia meridional: variabilidade e teleconexões extra-regionais. Confins. Revue franco-brésilienne de géographie / Revista franco-brasilera de geografia, n. 29, p. 2–9, 2016.

GAŠPAROVIĆ, I.; GAŠPAROVIĆ, M.; MEDAK, D. Determining and analysing solar irradiation based on freely available data: A case study from Croatia. Environmental Development, v. 26, p. 55–67, 1 jun. 2018.

GOBO, J. P. A.; GALVANI, E.; WOLLMANN, C. A. Influência Do Clima Regional Sobre O Clima Local a Partir Do Diagnóstico De Abrangência Espacial E Extrapolação Escalar. Revista Brasileira de Climatologia, v. 22, p. 210–228, 2018.

GÜÇLÜ, Y. S. Multiple Şen-innovative trend analyses and partial Mann-Kendall test. Journal of Hydrology, v. 566, n. September, p. 685–704, 2018.

HANIF, M.; KHAN, A. H.; ADNAN, S. Latitudinal precipitation characteristics and trends in Pakistan. Journal of Hydrology, v. 492, p. 266–272, 2013.

IBGE, 2020. IBGE: instituto Brasileiro de Geografa e Estatística. https://ww2.ibge.gov.br/home/geociencias/geografa/mapas_doc3.shtm.

IPAM, 2019. Desmatamento zero na Amazônia: como e por que chegar lá.

JUÁREZ, N. R. I.; GOULDEN, M. L.; MYNENI, R. B.; FU, R.; BERNARDES, S.; GAO, H. An empirical approach to retrieving monthly evapotranspiration over Amazonia. International

Journal of Remote Sensing, v. 29, p. 7045-7063, 2008. https://doi.org/10.1080/01431160802226026

KAISER, F. et al. Pinhão Manso (Jatropha curcas) como alternativa para a produção de biocombustíveis.Cascavel, 2016. Disponível em: <https://www.fag.edu.br/upload/revista/seagro/5834855371534.pdf>. Acesso em: 3 jul. 2019

KAISER, F. et al. Pinhão Manso (Jatropha curcas) como alternativa para a produção de biocombustíveis.Cascavel, 2016. Disponível em: <https://www.fag.edu.br/upload/revista/seagro/5834855371534.pdf>. Acesso em: 3 jul. 2019

Kaiser, H. F. (1960). The application of electronic computers to factoranalysis. Educational and Psychological Measurement, 20, 141–151.http://dx.doi.org/10.1177/001316446002000116

KHAN, S.; UL HASAN, M. Evapotranspiration Distribution and Variation of Pakistan (1931-2015). Annals of Valahia University of Targoviste, Geographical Series, v. 17, n. 2, p. 184–197, 2017.

LEITE, L. O. et al. ANÁLISE DA TEMPERATURA DO AR NOS MUNICÍPIOS DE HUMAITÁ E APUÍ, AM, PARA O ANO DE 2009. Revista EDUCAmazônia, v. XII, n. 1, p. 72–84, 2014.

LEVER, J.; KRZYWINSKI, M.; ALTMAN, N. Points of Significance: Principal component analysis. Nature Methods, v. 14, n. 7, p. 641–642, 2017.

LOPES, J. R. F.; SILVA, D. F. Aplicação Do Teste De Mann-Kendall Para Análise De Tendência Pluviométrica No Estado Do Ceará. Revista de Geografia (Recife), v. 30, n. 3, p. 192–208, 2013.

LOTUFO, J. B. DA S. et al. Índices Espectrais e Temperatura de Superfície em Áreas Queimadas no Parque Estadual do Araguaia em Mato Grosso. Revista Brasileira de Geografia Física, v. 13, p. 648–663, 2020.

LUMBAN-GAOL, Y. et al. Analysis on the Effect of Map Projection System for Area Calculation. IPTEK Journal of Proceedings Series, v. 0, n. 2, p. 69, 2019.

MAGALHÃES, I. B. et al. Brazilian Cerrado and Soy moratorium: Effects on biome preservation and consequences on grain production. Land Use Policy, v. 99, n. August, p. 105030, 2020.

MANN, H. B. Nonparametric Tests Against Trend. The Econometric Society, v. 13, n. 3, p. 245–259, jul. 1945.

MARENGO, J. A.; NOBRE, C. A. Clima da região amazônica. In: CAVALCANTI, I. F. A. (Org.). Tempo e Clima do Brasil. São Paulo: Oficina de Textos, p.198-212, 2009.

MARENGO, J. A.; SOUZA JR, C. Mudanças Climáticas : impactos e cenários para a Amazônia. Instituto Nacional de Ciência e Tecnologia (INCT) para Mudanças Climáticas Fase 2, v. 5, n. December, p. 1–33, 2018.

MARTINS, A. P. Relação entre uso e cobertura da terra e parâmetros biofísicos no Cerrado Brasileiro. Revista do Departamento de Geografia, v. 40, p. 148–162, 2020.

MATRICARDI, E. A. T.; SKOLE, D. L.; PEDLOWSKI, M. A.; CHOMENTOWSKI, W. & L. C. FERNANDES. 2010. "Assessment of tropical forest degradation by selective logging and fire using Landsat imagery". Remote Sensing of Environment, 114(5): 1.117-1.129.

MEDEIROS, R. M. DE et al. Temperatura média do ar e suas flutuações no Estado de Pernambuco, Brasil Raimundo. Revista Brasileira de Meio Ambiente, v. 2, n. 1, p. 81–93, 2018.

MORAES, D. Bioma Amazônia. p. 1–6, 2020.

MOREIRA, A. P. M.; SILVA, J. DA C. Influência do relevo e vegetação na variação da temperatura e umidade relativa do ar na Serra do Cipó - MG, em um estudo de curto prazo. Os Desafios da Geografia Física na Fronteira do Conhecimento, n. 1993, p. 1988–1999, 2017.

MOTOKI, K. et al. A influência da desintegração do radônio transportado pela evapotranspiração das plantas na formação de aerossóis atmosféricos em ambiente de florestas continental e insular. Brazilian Journal of Radiation Sciences, v. 8, n. 2, p. 1–11, 2020.

NASCIMENTO, L. L.; DE QUADROS, J. R. Do Tempo Do Direito Ao Tempo Dos Rios Voadores: As Águas Da Amazônia À Margem da Lei. Revista de Direito Ambiental e Socioambientalismo, v. 4, n. 2, p. 124, 2018.

NEPSTAD, D. C.; STICKLER, C. M.; SOARES-FILHO, B. & F. MERRY. 2008. "Interactions among Amazon land use, forests and climate: prospects for a near-term forest tipping point". Philosophical Transactions of the Royal Society B: Biological Sciences, 363(1.498): 1.737-1.746.

NOVILLO, C. J.; ARROGANTE-FUNES, P.; ROMERO-CALCERRADA, R. Recent NDVI trends in mainland Spain: Land-cover and phytoclimatic-type implications. ISPRS International Journal of Geo-Information, v. 8, n. 1, p. 5–7, 2019.

PAVÃO, L. L. et al. DISTRIBUIÇÃO ESPAÇO-TEMPORAL DA TEMPERATURA SUPERFICIAL URBANA NO SUL DO AMAZONAS. Raega - O Espaço Geográfico em Análise, v. 42, p. 210, 21 dez. 2017.

Pellegrini, F.R., Fogliatto, F.S., 2001. Passos para implantaç~ ao de sistemas de previs~ ao de demanda: técnicas e estudo de caso. Production 11, 43–64. https://doi.org/10.1590/ S0103-65132001000100004.

Pereira, O.J.R.; Ferreira, L.G.; Pinto, F.; Baumgarten, L. Assessing Pasture Degradation in the Brazilian Cerrado Based on the Analysis of MODIS NDVI Time-Series. Remote Sens. 2018, 10, 1761. https://doi.org/10.3390/rs10111761

PRATES, Rodolfo Coelho and BACHA, Carlos José Caetano. Os processos de desenvolvimento e desmatamento da Amazônia. Econ. soc. [online]. 2011, vol.20, n.3, pp.601-636. ISSN 0104-0618. http://dx.doi.org/10.1590/S0104-06182011000300006.

RIBEIRO, R. C.; OLIBEIRA, F. G. DE; ANJOS, C. S. DOS. Análise da resposta espectral da vegetação nativa do bioma. Anais XIVXsimposio brasileiro de sensoriamento remoto. Anais...Santos: INPE, 2019

RIOS VOADORES (2016). Disponível em: <http://riosvoadores.com.br/o-projeto/fenomenodos-rios-voadores/>. Acesso em: 19 jan. 2021.

Rivero, S., Almeida, O., Ávila, S., Oliveira, W., 2009. Pecuária e desmatamento: uma análise das principais causas diretas do desmatamento na Amazônia. Nova Economia 19 (1), 41–66.

ROCHA, V. M. et al. Reciclagem de Precipitação na Bacia Amazônica: O Papel do Transporte de Umidade e da Evapotranspiração da Superfície. Revista Brasileira de Meteorologia, v. 32, n. 3, p. 387–398, set. 2017.

ROCHA, V. M.; CORREIA, F. W. S.; GOMES, W. B. Avaliação dos Impactos da Mudança do Clima na Precipitação da Amazônia Utilizando o Modelo RCP 8.5 Eta-HadGEM2-ES. Revista Brasileira de Geografia Física, v. 12, n. 06, p. 2051–2065, 2019.

ROSA, I. M. D. et al. Predictive Modelling of Contagious Deforestation in the Brazilian Amazon. PLoS ONE, v. 8, n. 10, 2013.

RUDORFF, B. F. T. et al. The soy moratorium in the Amazon biome monitored by remote sensing images. Remote Sensing, v. 3, n. 1, p. 185–202, 2011.

SABINO-SANTOS, G. et al. Hantavirus antibodies among phyllostomid bats from the arc of deforestation in Southern Amazonia, Brazil. Transboundary and Emerging Diseases, v. 67, n. 3, p. 1045–1051, 2020.

SALAZAR LATORRE, N.; ARAGÃO, L. E. O. E C. DE; ANDRESON, L. O. IMPACTOS DE QUEIMADAS SOBRE DIFERENTES TIPOS DE COBERTURA DA TERRA NO LESTE DA AMAZÔNIA LEGAL BRASILEIRA. Revista Brasileira de Cartografia, v. 69, n. 1, 7 jan. 2017.

SALES, A. et al. Carbono Orgânico E Atributos Físicos Do Solo Sob Manejo Agropecuário Sustentável Na Amazônia Legal. Colloquium Agrariae, v. 14, n. 1, p. 01–15, 2018.

SANTOS, D.; MORAES, S. Variação Da Temperatura Do Ar Média, Mínima E Máxima No Perfil Topoclimático da Trilha Caminhos Do Mar (Sp). Revista Equador, v. 7, p. 01–09, 2016.

SATYAMURTY, P.; DA COSTA, C. P. W.; MANZI, A. O. Moisture source for the Amazon Basin: A study of contrasting years. Theoretical and Applied Climatology, v. 111, n. 1–2, p. 195–209, 2013.

SAYYAD, R. S.; DAKHORE, K. K.; PHAD, S. V. Analysis of rainfall trend of Parbhani , Maharshtra using Mann – Kendall test. Journal of Agrometeorology, v. 21, n. 2, p. 239–240, 2019.

SENEVIRATNE, S. I.; CORTI, T.; DAVIN, E. L.; HIRSCHI, M.; JAEGER, E. B.; LEHNER, I.; ORLOWSKY, B.; TEULING, A. J. Investigating soil moisture-climate interactions in a changing climate: A review. Earth Science Reviews, v. 99, p. 125–161, v. 2010. https://doi.org/10.1016/j.earscirev.2010.02.004

SERRÃO, E. A. DE O. et al. Influência do uso e cobertura da terra na variabilidade espacial e temporal da evapotranspiração no sudeste da Amazônia, utilizando o modelo SWAT. Revista Ibero-Americana de Ciências Ambientais, v. 10, n. 4, p. 134–148, 4 set. 2019.

Sparks, Tim & Menzel, Annette. (2002). Observed changes in seasons: An overview. International Journal of Climatology. 22. 10.1002/joc.821.

STUDER, S. et al. A comparative study of satellite and ground-based phenology. International Journal of Biometeorology, v. 51, n. 5, p. 405–414, 2007.

TERRSET. Geospatial Monitoring and Modeling SystemClarck Labs, 2020. Disponível em: <https://www.geocarto.com/TerrSet_Brochure.pdf>

UDDIN, M. N. et al. Mapping of climate vulnerability of the coastal region of Bangladesh using principal component analysis. Applied Geography, v. 102, n. December 2018, p. 47–57, 2019.

VIEIRA, I. C. G.; TOLEDO0, P. M.; SILVA, J. M. C & H: HIGUCHI. 2008. “Deforestation and threats to the biodiversity of Amazonia”, Brazilian Journal of Biology, 68(4): 949-956.

ZHANG, Z. et al. Using principal component analysis and annual seasonal trend analysis to assess karst rocky desertification in southwestern China. Environmental Monitoring and Assessment, v. 189, n. 6, 2017.

Chapter 3 - Cultivation of oilseeds in degraded areas in the Legal Amazon for soil recovery and biodiesel production.

Abstract

The agricultural activity growth in Brazil has generated major environmental problems within the natural scenario of the country. In the Legal Amazon, which is 5,217,423 km² (61% of Brazilian territory), about 20% of the degraded areas result from the expansion of the agricultural frontiers for implementation of agriculture and livestock activities. Those uncontrolled levels of degradation are on the verge of reaching a limit that will cause irreversible changes in the natural patterns of this area. In order to reverse the current degradation scenario, this work aimed to select the best areas for oil palm and/or jatropha cultivation in degraded areas of the Legal Amazon. The multicriteria analysis considered geospatial, environmental and socioeconomic factors. The conflict areas were obtained through the CROSSTAB algorithm. The MOLA algorithm was used to solve problems of land allocation in conflicting situations. It compared the yield, recovery capacity and economic viability of these crops for biodiesel production. The analyses showed that the palm, as compared to jatropha, is the best cultivation option within the study area, since it allows the recovery of degraded areas, and it also has low production and maintenance costs, presenting higher profit and productivity of raw material, as well as greater oil production when compared to jatropha.

Keywords: Legal Amazon, Degraded Areas, Recovery of areas, Oilseeds, Biodiesel.

1. Introduction

The Legal Amazon has suffered environmental impacts associated with the high levels of degradation generated by agricultural growth and the increase of extractive trade. The growth of agricultural activity in Brazil has generated serious environmental problems in the country's natural landscapes. Around 20% of the degraded areas of the Legal Amazon result from the expansion of the agricultural frontier for the implementation of agricultural and livestock activities. Those uncontrolled levels of deforestation are close to reaching a limit that will provide irreversible changes in the natural patterns of the Amazon rainforest (IPAM, 2017).

This work aims to select the best-suited degraded areas of the Legal Amazon for palm and/or jatropha cultivation. For the selection of these areas, geospatial, environmental and socioeconomic factors were considered. The analysis compared the productivity, area recovery capacity and economic viability for biodiesel production, for both types of cultivation.

The expansion of agricultural activity in Brazil, between 2000 and 2010, was the major cause of deforestation (Moutinho et al., 2012). Florest devastation, caused by the intensification of this expansion, already covers an area of 77,520 km² (68% of total), with pastures accounting for 28% of deforestation (32,120 km²) (IBGE, 2015).

Tavora (2015) affirms that the growth of livestock and the expansion of soy production result in high social impacts, as well as the conversion of native vegetation cover (cerrado, transitional forests and tropical forests of high biological value) and contamination of aquatic, terrestrial and atmospheric conditions.

Studies of the Grupo de Trabalho sobre Florestas do Fórum Brasileiro de ONGs e Movimentos Sociais para Meio Ambiente e Desenvolvimento (FBOMS, 2014), indicate that, during the period from 2010 to 2012, changes in the natural landscape came to represent 3.5% of the national territory. This transformation, which took place in just two years, is equivalent to half of that observed in the 10-year period (IBGE, 2015), revealing acceleration in the processes of change in land cover and land use in the country, with the exponential growth of Amazonian degradation levels.

Botelho et al. (2007) state that a degraded ecosystem is one that, after modifications in the natural conditions, has eliminated, together with the vegetation, its means of biotic regeneration. Thereby, its return to the previous state cannot occur. In this case, the anthropic action is necessary for its recovery in the short term. This recovery can occur through works on the ground such as the construction of terraces and banquettes and with the implantation of plant species (Veloso et al., 2010)

Among all natural recovery methods, natural regeneration is the cheapest one. However, it is more time-consuming (Kohlrausch and Jung, 2015). Firstly, perennial species must be planted, capable of growing on poor soils with little vegetation coverage, providing shade, organic matter and soil protection, so other native plants with higher sensibility to sunlight can start growig again (Nobre et al., 2016).

In order to reverse the current degradation scenario, the cultivation of oilseeds appears as an option for the recovery of degraded areas. Some oilseeds (palm, jatropha, castor bean, sunflower, among others), besides aiding in reforestation, are sources of large amounts of oil for the production of biodiesel. For example, the same area for production of palm can produce eight times more biodiesel than soy (BiodieselBR, 2014). Palm or jatropha cultivation in degraded areas allows it to intercalate with other crops (pineapple, banana, cassava and acai, for example), contributing to food production and improving soil quality (Rocha et al., 2007).

Biodiesel is very interesting from an environmental point of view because its blend with petrodiesel (diesel derived from petroleum) reduces the emission of particulate matter, hydrocarbons and carbon monoxide by up to 20% (Dunn, 2010). Because its production is from organic matter and not from fossil fuels, there is a significant reduction in the emission of carbon into the atmosphere.

According to Osaki (2011), a much smaller amount of biodiesel is produced in the world when compared to ethanol. Unlike ethanol, whose production is most concentrated in Brazil and the United States, the production of biodiesel is diversified and distributed in multiple countries. Several raw materials are used for the production of biodiesel. They vary according to cost and availability in each country. In the USA, soybean oil and animal fat are used, and in the European Union, rapeseed and sunflower seed are used (Dunn, 2010).

Brazil occupies the third place in the world ranking of biodiesel production, being behind the United States and Germany, which occupy the first and second positions, respectively. In the national scenario, the Center-West region leads the ranking of largest producers of biofuel. Mato Grosso is the state with the highest production, followed by the South and Northeast, which present Rio Grande do Sul and Bahia as the highest productors, respectively (BiodieselBR, 2014).

According to Araujo (2005), soy is responsible for more than 82% of biodiesel production in Brazil. However, the need for production generates an increase of cultivation within new areas, implying the expansion of the agricultural frontier and, consequently, generating new deforestation sites.

Within the current energy scenario, together with public policies aimed at preserving the environment and reducing environmental impacts, biodiesel appears as an economic alternative and promising potential to meet energy production deficiencies, with positive impacts in both environmental and social terms. The production of biofuels contributes to the reduction of greenhouse gas (GHG) release, as it allows the use of cleaner fuel, which makes use of organic sources in the production, which also minimizes the consumption of fossil fuels.

The potential use of biodiesel combined with the current demands for less-polluting fuel sources can be explored through tools that allow the integration of data and evaluate the use of areas with minimal impact to the environment. Among these tools, the Geographic Information Systems (GIS) stands out.

GIS allows the aggregation of spatial information on maps, as well as processing, analyzing and linking data that contribute, for example, to the identification, implementation and management of biodiesel-producing areas, finding the best production flow routes, setting up new power plants, among other facilities.

2. Methodology

Figure 1 presents the methodology used on this article:

1. Delimitation of the study area, based on geospatial, environmental and socioeconomic conditions;
2. Construction of the spatial database;
3. Assessment of the environmental conditions necessary for the cultivation of jatropha and palm;
4. Uniformity, data processing and multicriteria analysis application;
5. Comparison of the results obtained and definition of the best areas and best crop to apply in the study area.

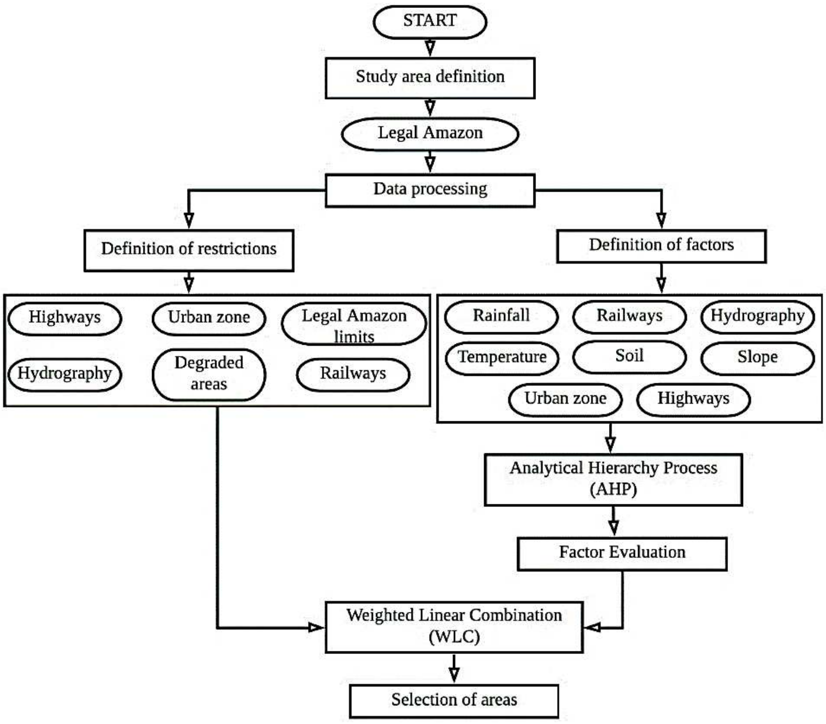

Figure 1: Methodological scheme and data source.

2.1 Study area delimitation

According to the Brazilian Institute of Geography and Statistics, the Legal Amazon presents an area of 5,217,423 km², which corresponds to 61% of the Brazilian territory. In addition to housing the entire Brazilian Amazon biome, it also contains 20% of the Cerrado biome and part of the Pantanal Mato-grossense. The states of Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima and Tocantins are all in this region, which also covers part of the state of Maranhão.

The study area is limited to the degraded areas contained within the limits of the Legal Amazon, as can be seen in Figure 2.

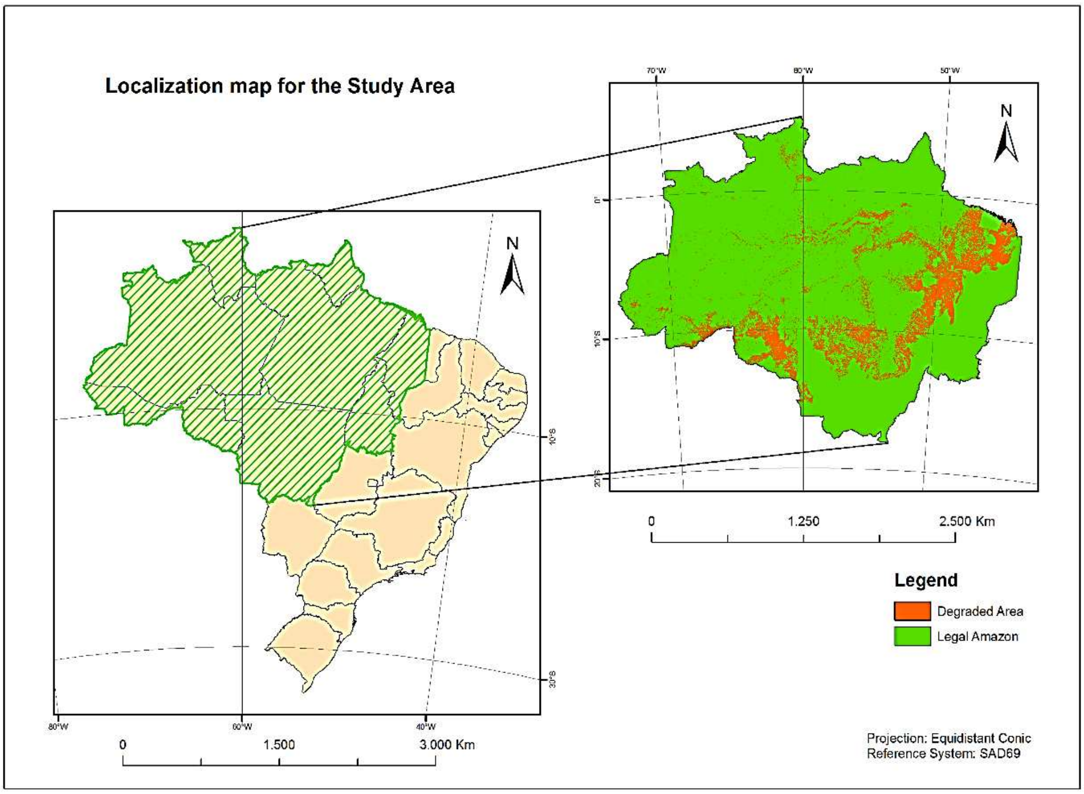

Figure 2: Study area definition.

2.2 Cultivation conditions, and analytic restrictions and factors

2.2.1 Cultivation conditions

The environmental conditions necessary for the insertion of palm and jatropha crops within the Legal Amazon area were evaluated, considering that these crops, besides recovering degraded areas, are biodiesel-producing sources.

Table 1 shows the parameters analyzed for the viability of these crops.

PRODUCTION DATA	PALM	JATROPHA
Anual preciptation	1800–2000 mm/year	≥ 600 mm/year
Average temperature	20–28 °C	20−27 °C
Slope	≤ 5°	≤ 30°
Soil type	Clay latosol	Sandy latosol / Medium / Mixed

Information source	CEPLAC - Executive Committee of the Cocoa Plan	IPA - Agronomic Institute of Pernambuco

Table 1: Crop parameters of palm and jatropha.

2.2.2 Restrictions and factors

The multicriteria analysis allows us to find suitable areas for implementation of projects, such as the one proposed in this study, based on factors and constraints. These, when inserted in the analysis, allow the selection of suitable areas, within the evaluated criterias.

Table 2 shows the restrictions used in the analysis.

RESTRICTION	JUSTIFICATION
Legal Amazon limits	The analysis must be performed within the limits of the study area.
Degraded areas	To avoid expansion of the agricultural frontier, degraded areas are introduced in the analysis to ensure that all selected areas are properly inserted in the study area and do not conflict with the other agricultural regions.
Urban zone	The selected areas must be distant from the commercial centers and cities, while preserving a proximity to the commercialization of the production.
Highways	The selected areas must be distant from the highways, while preserving a proximity to the final product outflow.
Railways	The selected areas must be distant from the railways, while preserving a proximity to the final product outflow.
Hydrography*	According to the Ministério do Meio Ambiente, law nº 12.651, of May 25th of 2012, there must be a minimum distance of 300 meters from the banks of large rivers.

*The waterways were not presented in the restrictions, since they are inserted in hydrographic data. Vessels use the same rivers and large water bodies already considered in the hydrographic data.

Table 2: Restrictions used and justifications.

Factors are presented in Table 3.

FACTOR	CHARACTERZATION
Rainfall	Palm: 1800–2000 mm/year; Jatropha: ≥ 600 mm/year
Temperature	Palm: 20–28 °C; Jatropha: 20–27 °C
Soil type	Inserted in areas that presents the specific type of soil of each crop.
Hydrography	500 kilometers from the closest river
Highways	500 kilometers from the closest highway
Railways	500 kilometers from the closest railway
Waterways	kilometers from the closest waterway
Urban zone	kilometers from the closest cities
Slope	Palm: slope ≤ 5°; Jatropha: 5° ≤ slope ≤ 30°

Table 3: Factors applied in the multicriteria analysis.

Conservation units, indigenous territories, and quilombola areas, among others, were not considered as restrictions, since the activity is not classified as extractivism but rather as a recovery process adding to the generation of a final product with potential commercialization.

2.3 Data processing and analysis

Editing of vector data and standardizing matrix data was done in ArcGIS© software. Constraints and factors were combined with the objective of finding the most suitable growing areas in IDRISI software. Figure 3 shows the simplified flowchart of multicriteria analysis applied.

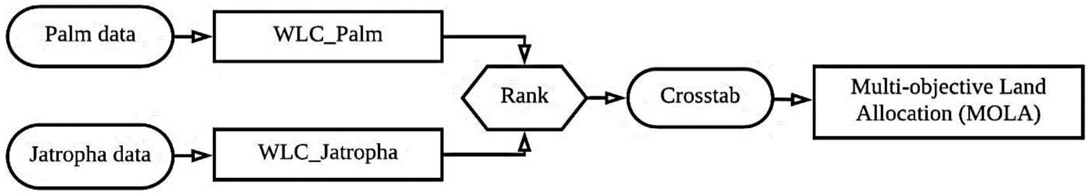

Figure 3: Simplified processing flowchart in IDRISI software.

According to Pinto et al. (2014), the multicriteria analysis seeks to prioritize not only the biological aspects and the heterogeneity of the study area but also the socioeconomic desires of the population and the menace to land use.

In order to process the data, the spatial data related to jatropha and palm cultures were first inserted in IDRISI software. Multicriteria evaluation (MCE) was used, with the process of aggregation of weighted linear combination (WLC). The resulting images from WLC were ordered with the RANK algorithm. The conflict areas between the two cultures were identified using the CROSSTAB algorithm. The multi-objective land allocation algorithm (MOLA) was used as a decision aid in the allocation of competing and/or overlapping areas.

2.4 Integration, analysis and comparison of obtained data

After the selection of the areas, based on the planting conditions provided by IPA and CEPLAC, a comparative analysis was carried out between jatropha and palm cultivation, in relation to productive capacity and economic viability. Using qualitative and quantitative data, the viability of the cultures was obtained in relation to the insertion and production in the study area.

2.5 Economic analysis of cultivation

This study performed an economic viability analysis for three growing periods (1, 3 and 10 years, respectively), as well as the average financial return from the sale of the generated product. These periods were defined in order to evaluate how palm oil production and *Jatropha curcas* behave over time, based on data already available in the literature. Because they are perennial crops, they have different levels of productivity and care according to their maturity. Thus, a period of planting insertion, a growth phase, and another period under mature conditions at the peak of production were used.

First and third year production costs were taken from the literature (Abrapalma, 2018; CECOR/CATI, 2019; and Conab, 2019). The costs of the tenth year were calculated using a forecasting function, which calculates or predicts a future value from existing values, where the new value is predicted by linear regression (Office, 2016). Pellegrini and Fogliatto (2001), state that forecasting techniques make it possible to perform mathematical modeling using existing data, allowing predictions to be made accurately, unlike those based on intuition.

Soybean yield data, as well as its economic viability, were included in the comparative analysis, as it is the most widely used biodiesel source in Brazil today.

3. Results and Discussion

After identifying areas suitable for the cultivation of oil palm and jatropha in degraded areas of the Legal Amazon, with the aid of the CROSSTAB algorithm suitable areas for planting both crops were identified (Figure 4). These areas represent about 56.8 million hectares. Within the study area, in addition to the areas that serve the cultivation of the two cultures (conflict areas), palm is suitable for cultivation in about 540 thousand hectares of degraded areas, and that of jatropha in approximately 773 thousand hectares.

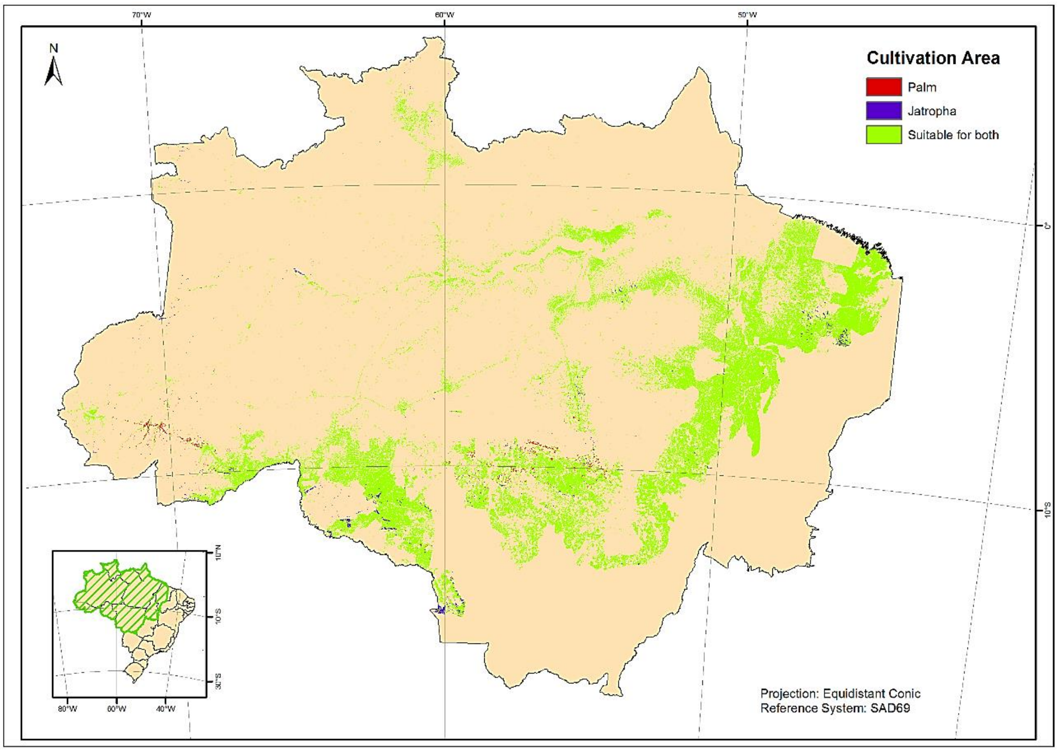

Figure 4: Suitable areas for palm and jatropha cultivation.

The MOLA algorithm, used to solve problems of land allocation in conflicting situations (in the case of crops, similar cultivation conditions), was applied considering three scenarios. One allocating 50% of the area for each crop, another allocating 70% of the area for palm and 30% for jatropha, and the last allocating 70% for jatropha and 30% for palm (Figure 5). Allocation ratios in the MOLA algorithm with the same weight for the two crops and two with significantly different weights allowed the economic evaluation for the implantation of the crops, considering that, for the environmental recovery criteria, both are presented as viable.

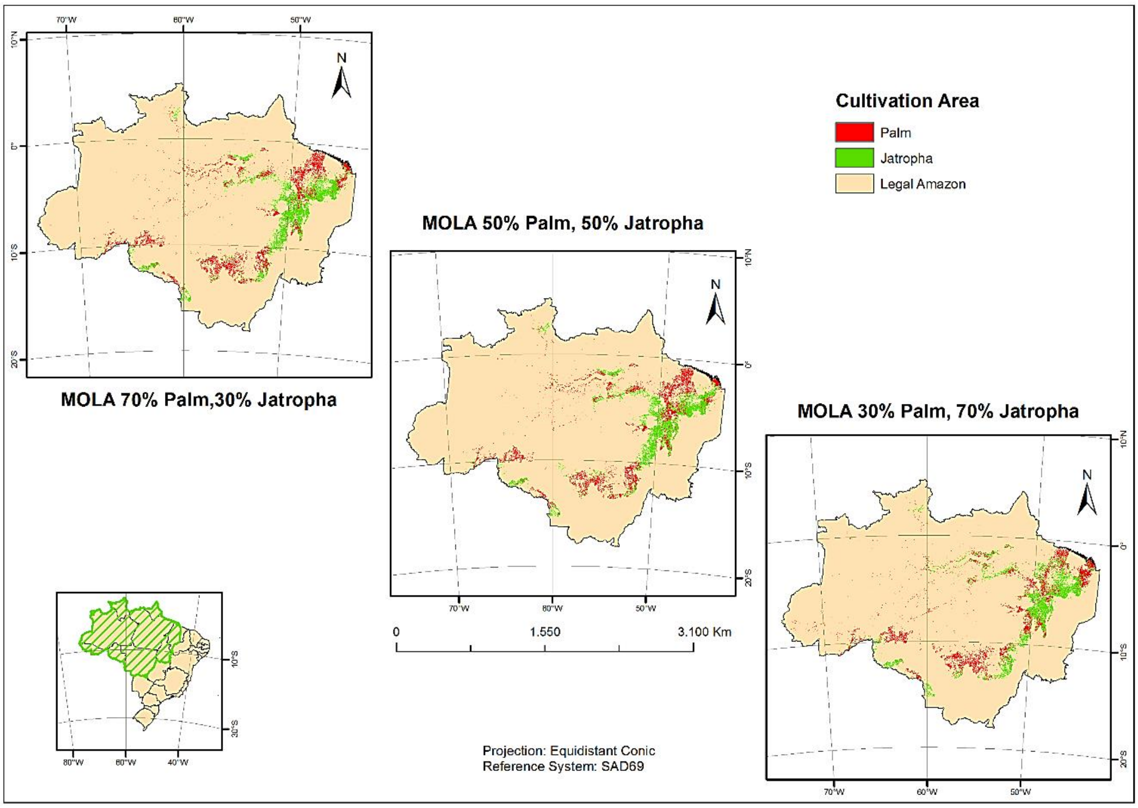

Figure 5: MOLA algorithm results.

From the conflict areas identified by the CROSSTAB, only 30% was used in the MOLA algorithm. These areas are the result of the classification of the cells with the highest adequacy, that is, these 30% represent the best regions for the cultivation of palm and/or jatropha. Thus, if one of these crops (or both crops) were inserted within the study area, these 30% would represent the best areas to start the recovery process of degraded areas.

The literature has applied multicriteria analysis with the MOLA algorithm to identify better areas for many different objectives (Hajehforooshnia et al., 2011; Mustafa et al., 2011; Correia, 2013; Kazemi et al., 2016). As in this study, the results were satisfactory and support the methodology used.

The crops used in this study were selected due to their cultivation characteristics: they are not very demanding in relation to the soil; they can be cultivated in degraded soils, allowing their recovery from the input of the organic matter supplied, create preferential channels developed by the roots, favoring the emergence of the microbiota; besides presenting high biodiesel production.

Table 4 presents the costs applied for each growing season, the amount of oil produced and the sale value of the final products per hectare planted.

	PALM	JATROPHA	SOY
Planted area (ha)	1.00	1.00	1.00
First year production costs* ($)	$ 632.80	$ 1386.19	$ 907.98
Second year production costs * ($)	$ 455.19	$ 929.25	$ 719.56
Third year production costs * ($)	$ 209.21	$ 182.32	$ 274.18
Oil productivity per hectare* (Ton/ha)	8.7	2.4	3.33
Oil sales price* ($/ton)	$ 713.00	$ 145.00	$ 358.00
Final profitability ($)	**$ 6,203.10**	**$ 348.00**	**$ 1,193.21**

* The cost data of years 1 and 3 were taken from EMBRAPA, 2018. The productivity data were extracted from (Abrapalma, 2018), (CECOR/CATI, 2018) and (Conab, 2019), respectively. The sale value was taken from ANP (2018).

Table 4: Economic viability of oilseeds crop per hectare planted.

As can be seen in Table 4, palm presents the lowest production costs, besides greater profitability after the processing of the raw material generated. Thus, relying on the financial appeal, and considering that the environmental recovery power of the two cultures is the same, it can be concluded from the data presented that palm cultivation is the best option for the degraded areas of the Amazon.

In Indonesia, the insertion of the palm as a biodiesel production crop has brought drastic problems to the country (Austin et al., 2018). One of them was the competitiveness of areas destined for the production of food that were directed to the cultivation of palm, decreasing the alimentary production. Another problem brought by this cultivation was the increase of deforestation levels, with the removal of the native forest to insert the oilseed crop.

In this proposal, the palm proves to be a very viable crop, as it does not compete with areas destined for agriculture. It contributes to the recovery of degraded areas already existing. It maintains the quality of the soil. Besides, there is the high productivity of oil with high power for production of biofuels.

4. Conclusion

Spatial analysis showed that most of the degraded areas of the Legal Amazon could be used for oil palm and/or jatropha cultivation since they meet the minimum parameters required for the planting of these species. Thus, the implementation of a degraded area recovery plan of these areas by applying the planting of these species is viable as they are perennial crops, with large trees providing organic matter, nutrients and shade for the reappearance of native species. Another point to highlight in this study is the production without expansion of the agricultural frontier, because the proposal is the cultivation in areas already depleted of nutrients.

5. Acknowledgements

This work was carried out with the support of CAPES - Financing Code 001

References

Abrapalma, 2018. Diagnóstico de Produção Sustentável da Palma de Óleo. Mapa/ACE, Brasília, p. 58.

ANP, 2018. Anuário estatístico brasileiro do petróleo, gás natural e biocombustíveis, in: Machado, J.C. de S., Ferraz, L.H.V., Moraes, R., Torres, R.D. (Eds.), Agência Nacional de Petróleo, Gás Natural e Biocombustíveis. ANP, Rio de Janeiro, p. 265.

Araujo, R.M. de, 2005. Regulação do Biodiesel - Especificações e Controle de Qualidade.

Austin, K.G., Mosnier, A., Pirker, J., McCallum, I., Fritz, S., Kasibhatla, P.S., 2017. Shifting patterns of oil palm driven deforestation in Indonesia and implications for zero-deforestation commitments. Land use policy 69, 41–48. https://doi.org/10.1016/j.landusepol.2017.08.036

BiodieselBR, 2014. Biodiesel no Mundo [WWW Document]. URL https://www.biodieselbr.com/biodiesel/mundo/biodiesel-no-mundo (accessed 6.10.19).

Botelho, S.A., Ferreira, W.C., Davide, A.C., Faria, J.M.R., 2007. Avaliação do crescimento do estrato arbóreo de área degradada revegetada à margem do Rio Grande, na Usina Hidrelétrica de Camargos, MG. Rev. Árvore 31, 177–185. https://doi.org/10.1590/S0100-67622007000100020

CECOR/CATI, 2018. Revista Casa da Agricultura. CECOR/CATI, São Paulo, p. 52.

Conab, 2019. Preços Agropecuários - COMPANHIA NACIONAL DE ABASTECIMENTO [WWW Document]. URL https://www.conab.gov.br/info-agro/precos (accessed 6.25.19).

Correia, L.G.B., 2013. A utilização da análise multicritério no software dinâmica ego para definição de áreas favoráveis para o cultivo do Mogno Africano (Khaya ivorensis) no estado de Minas Gerais. 13, 124.

Dunn, R.O., 2010. Other Alternative Diesel Fuels from Vegetable Oils and Animal Fats, in: The Biodiesel Handbook. Elsevier, pp. 405–437. https://doi.org/10.1016/B978-1-893997-62-2.50015-2

Grupo de Trabalho sobre Florestas do Fórum Brasileiro de ONGs e Movimentos Sociais para Meio Ambiente e Desenvolvimento - FBOMS, 2014. Relação entre cultivo de soja e desmatamento COMPREENDENDO A DINÂMICA SUMÁRIO EXECUTIVO. São Paulo.

Hajehforooshnia, S., Soffianian, A., Mahiny, A.S., Fakheran, S., 2011. Multi objective land allocation (MOLA) for zoning Ghamishloo Wildlife Sanctuary in Iran. J. Nat. Conserv. 19, 254–262. https://doi.org/10.1016/j.jnc.2011.03.001

IBGE, 2015. IBGE :: Instituto Brasileiro de Geografia e Estatística [WWW Document]. URL https://ww2.ibge.gov.br/home/geociencias/geografia/mapas_doc3.shtm (accessed 6.12.19).

IPAM, 2017. Desmatamento zero na Amazônia: como e por que chegar lá.

Kazemi, H., Sadeghi, S., Akinci, H., 2016. Developing a land evaluation model for faba bean cultivation using geographic information system and multi-criteria analysis (A case study: Gonbad-Kavous region, Iran). Ecol. Indic. 63, 37–47. https://doi.org/10.1016/j.ecolind.2015.11.021

Kohlrausch, F., Jung, C.F., 2015. Áreas Ambientais Degradadas: Causas E Recuperação, in: XI Congresso Nacional de Excelência Em Gestão. Rio de Janeiro, p. 22.

Moutinho, P., Pak, T., Klabin, I., Kelman, J., Luiz Alquerés, J., Silvia Bastos Marques, M., Reichstul, P., Ricupero Thomas Lovejoy, R., Saporta, L., Gemunder, L., Mattos, T., Giannotti, L., Lima, C., Estúdio, E., Noury, C., Célem, L., Lelo, M., 2012. Redução de emissões por desmatamento e degradação florestal (REDD+): construindo os alicerces da economia verde no Brasil.

Mustafa, A.A., Singh, M., Sahoo, R.N., Ahmed, N., Manoj;, K., Sarangi, A., Mishra, A.K., 2011. Land Suitability Analysis for Different Crops: A Multi Criteria Decision Making Approach using Remote Sensing and GIS. Researcher 3, 61–84. https://doi.org/10.7537/marsrsj031211.14

Nobre, C.A., Sampaio, G., Borma, L.S., Castilla-Rubio, J.C., Silva, J.S., Cardoso, M., 2016. Land-use and climate change risks in the Amazon and the need of a novel sustainable development paradigm. Proc. Natl. Acad. Sci. 113, 10759–10768. https://doi.org/10.1073/pnas.1605516113

Office, 2016. PREVISÃO (Função PREVISÃO) - Suporte do Office [WWW Document]. URL https://support.office.com/pt-br/article/previsÃo-função-previsÃo-50ca49c9-7b40-4892-94e4-7ad38bbeda99 (accessed 6.10.19).

Osaki, M., Batalha, M.O., 2011. Biodiesel and vegetable oil production in Brazil: reality and challenge 227. Organ. Rurais Agroindustriais 2, 227–242.

Pellegrini, F.R., Fogliatto, F.S., 2001. Passos para implantação de sistemas de previsão de demanda: técnicas e estudo de caso. Production 11, 43–64. https://doi.org/10.1590/S0103-65132001000100004

Pinto, F., Barbosa, R.I., Keizer, E.H., Campos, C., Lamberts, A., Souza, B., Azevedo, R.B., Borges, O.B., Marinho Brasil, S.B., Cardoso, G.C., Macedo, L., 2014. Multi-criteria analysis to select site to a protected area in the largest savanna of the Amazonia. Acta Geográfica 8, 50–70.

Rocha, R.N.C., Rodrigues, M. do R.L., Macêdo, J.L.V. de, Lopes, R., Teixeira, P.C., Lima, W.A.A. de, 2007. Análise financeira do custo de produção do dendezeiro (elaeis guineensis jacq.) em monocultivo e intercalado com abacaxi (ananas comusus l. merril) em áreas degradadas na Amazônia Ocidental, in: 4° Congresso Brasileiro de Plantas Oleaginosas, Óleos, Gorduras e Biodiesel. Varginha, pp. 702–708.

Tavora, R.P., 2015. A expansão da soja na Amazônia e as suas consequências. Universidade Candido Mendes, Niteroi.

Veloso, M.E. da C., Araújo, E.C.E., Silva, P.H.S. da, 2010. Recuperação de Áreas Degradadas em Gilbués - PI. Teresina - PI.

GENERAL CONCLUSION

The results of this research corroborate to the strand that, in the Legal Amazon, the forest has control over local climate. Changes caused by increased levels of anthropic action have a direct impact on vegetation, increase deforestation rates and cause variations in temperature and rainfall. It was also observed that the failure to adopt actions to control the suppression of natural vegetation increases deforestation, causing greater changes in NDVI levels, reflecting the malfunctioning of the hydrological cycle and impacts on thermal control.

In addition, it was observed that there are several factors that influence the climate of the Amazon. According to the analysis of the PCA, factors such as latitude, anthropic actions, relief and maritimity are the ones that most cause changes in the region, modifying climate behavior. These factors, added to others also active in the region, work together to potentiate the climatic changes of this biome. The STA analysis showed the interrelationship between the studied variables, allowing observing their seasonal behavior and the reflection of anthropic activities in the region's climatic scenario. In this context, it was possible to conclude that the climatic variables have a natural tendency that is directly modified by activities such as agriculture and pasture. Thus, anthropic actions induce the transformation of the landscape, mainly by burning applied in soil management, causing impacts on the regional climate, reflecting on climate changes on a national and global scale over time.

Given the above, ways of recovering the degraded area become a necessity for the study area. The spatial analysis showed that a large part of the degraded areas of the Amazon biome could be used for the cultivation of oil palm and/or jatropha, as they meet the minimum parameters required for the planting of these species. Thus, the implementation of a recovery plan for degraded areas of these areas with the application of these crops becomes viable because they are perennial crops, with large trees providing organic matter, nutrients and shade for the reappearance of native species. Another point to highlight in this study is the production of raw material for biodiesel without expanding the agricultural frontier, contributing environmentally and economically to the region.

SUGGESTIONS FOR FUTURE RESEARCH

This study showed that, in the Amazon biome, human activities directly affects climate variables, causing changes in them. It was possible to observe, according to the variables studied, their behavior in relation to the environmental variable NDVI, concluding that the presence of the forest is an important factor for maintaining the hydrological cycle and thermal control of the region and the globe.

However, the factors addressed in this study are not the only assets in the region. The climate of the Amazon region is a function of several variables that range from the conditions of the underground characteristics to the atmosphere. In this context, exploring other databases such as air and soil moisture, runoff, continentality, air masses, sea currents, among others, appears as a way to understand this ecosystem and its functionality for complete.

Regarding the scope of degraded areas recovery, the study showed the potential of oilseeds in this process and their economic viability for the production of biodiesel. However, there are other species, such as fruit trees and tubers, which can be applied in the recovery process and enable the financial return from the commercialization of the product produced. Thus, identifying other forms of recovery for this area allows for productive diversification, socioeconomic development, non-expansion of the agricultural frontier and reduction of human impacts on this biome.

APÊNDICE A

AMARAL E SILVA, A. et al. Anthropic activities and the Legal Amazon: Estimative of impacts on forest and regional climate for 2030. Remote Sensing Applications: Society and Environment, v. 18, n. March, p. 100304, abr. 2020.

Remote Sensing Applications: Society and Environment 18 (2020) 100304

Contents lists available at ScienceDirect

Remote Sensing Applications: Society and Environment

journal homepage: http://www.elsevier.com/locate/rsase

Anthropic activities and the Legal Amazon: Estimative of impacts on forest and regional climate for 2030

Arthur Amaral e Silva *, Matheus Quintão Braga, Juliana Ferreira, Vitor Juste dos Santos, Sabrina do Carmo Alves, Júlio César de Oliveira, Maria Lucia Calijuri

Federal University of Viçosa, Department of Civil Engineering, S/n. Campus UFV, 36571-000, Matheus Quintão Braga, Federal University of Viçosa, Brazil

ARTICLE INFO

Keywords:
Legal amazon
Anthropic activity
Deforestation
Remote sensing
Climate change

ABSTRACT

Created by the Law N° 1,806 of 1953 and updated to its original format by the Complementary Law N°. 31 of 1977, the Legal Amazon covers an area of approximately 5.2 million km², comprises nine Brazilian states, corresponding to around 61% of all Brazilian territory. In addition to the Amazon biome, the Legal Amazon covers part of Cerrado and Pantanal biomes. This region has suffered several impacts caused by the introduction of anthropic activity, mainly agriculture, leading to a high deforestation rate. As a way to mitigate the impacts in these areas, this paper aims to identify the possible variations in climatic variables and in the Legal Amazonian Normalized Difference Vegetation Index (NDVI), generated from the increase of anthropic action. As well as to outline the predicted deforestation scenario and the anthropic activity for 2030, allowing an association between impact increase, the aforementioned variations and the level of degradation. To achieve the goals outlined here, the methodology is divided into 3 steps: definition of the study area, data collection and standardization, and processing and comparison of the data obtained (using the Land Change Modeler and Earth Trend Modeler interfaces). The results of this research corroborate to observe that, in the Legal Amazon, the forest has control over the climate. Changes caused by higher levels of anthropogenic action have a direct impact on vegetation; increase deforestation rates and cause temperature and rainfall variations. Was concluded that the non-adoption of actions to control natural vegetation removal increases deforestation, causing greater changes in NDVI levels, greater changes in the hydrological cycle and thermal control.

1. Introduction

The Legal Amazon, created by the Law N° 1,806 of 1953 and updated to its current format by the Complementary Law N°. 31 of 1977, corresponds to an area of 5,217,423 km² covering nine Brazilian states, which corresponds to about 61% of the national territory (IBGE, 2015). Such delimitation includes, besides the Amazon rainforest, part of the Pantanal and Cerrado biomes (Filho and Souza, 2009). This area has suffered great impacts through the insertion of anthropic activities, leading to a deforestation rate, in 2018, higher than 7,500 km², with state of Pará hit the hardest (Barbosa and Lakshmi Kumar, 2016).

According to Ferreira and Coelho (2015), deforestation in the Legal Amazon relates to several factors, among them, commercialization of agricultural products, failing government policies, impacts of urban expansion, increased agricultural activity and arson. Agricultural activity, responsible for about 40% of degraded or undergoing degradation areas, contributes to almost 70% of total greenhouse gas emissions (Veloso et al., 2010), and stands out in the increase of Legal Amazon degradation. Logging is one of the most profitable economic activities of states within the limits of the Legal Amazon, and is responsible for vegetation removal (Kingo and Homma, 2015).

Nóbrega (2014) states that intense extraction of natural vegetation in the Amazon can cause irreversible regional, national and global damage, since such removal may affect rainfall regime, as well as result in temperature variations.

Several authors discuss the relationship between climate and forest formation in the Legal Amazon (Molion, 1987; Fisch et al., 1998; Santos et al., 2017; Alves, 2018; Andreola Serraglio et al., 2019), bringing different opinions on the subject. Some claim that rainfall and temperature are directly associated with the forest's natural state. Others affirm

* Corresponding author.

E-mail addresses: arthur.amaral@ufv.br (A. Amaral e Silva), matheusquintaobraga@gmail.com (M.Q. Braga), juliana.lorentz@gmail.com (J. Ferreira), vjustedossantos@gmail.com (V. Juste dos Santos), sabrinacarmoalves@gmail.com (S. do Carmo Alves), oliveirajc@ufv.br (J.C. de Oliveira), lucia.calijuri@gmail.com (M.L. Calijuri).

https://doi.org/10.1016/j.rsase.2020.100304
Received 4 February 2020; Received in revised form 16 March 2020; Accepted 18 March 2020
Available online 21 March 2020