Mesopotamia Journal of Agriculture

https://magrj.uomosul.edu.iq

USING REMOTE SENSING TECHNIQUES TO ANALYSE THE FACTORS CONTROLLING FOREST FIRES IN THE EASTERN AMAZON

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Article information
Article history:
Received: 18/10/2025
Accepted: 30/03/2026
Available: 31/03/2026

Keywords:
Forest degradation, Forest fires, Spatial analysis, Brazilian Amazon.

DOI:
10.33899/mja.2026.166052.1763

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ABSTRACT

Different factors linked to the human activities of the territory can have an impact on the degradation of the forest like the size of the properties and the proximity of roads, towns, and villages. They determine forestry and agricultural practices, accessibility (for the exploitation of ligneous resources in forestry), and the diffusion of fire phenomena. In this article, we will be interested in the spatial convergence of indicators on the distribution of forest fires at the scale of Paragominas municipality (Eastern Brazil). The spatial analysis will lead us to evaluate the role of explanatory factors in the distribution of fires at the municipal level. whether the size of agricultural or forest properties, distance to paved roads, and distance to towns and villages matter in forest fire activities.

INTRODUCTION

Global forest disturbances are increasing faster than expected. It's often led to forest fragmentation or deforestation. These disorders vary in severity and frequency. They can be episodic or semi-permanent depending on changes in environmental conditions.

Forest degradation results from one or more disturbance events over a given period. These disturbances can be of various kinds: logging, removal of wood or non-wood products from the forest, hunting, fires, changes in environmental conditions (following forest fragmentation for example), etc. They can be occasional (logging) or quasi-permanent (changes in environmental conditions or hunting).

In the Brazilian Amazon, forest fires, fragmentation due to the opening up of agricultural land, the selective exploitation of timber, the collection of firewood for the production of charcoal and grazing under forest cover are the main disturbances responsible for forest degradation (Hosonuma, *et al*., 2012) Even low-intensity fires

alter the composition and structure of the forest (Xaud*, et al*., 2013). Selective logging also alters forest cover, creating logging gaps and skidding trails. Logging injures trees, leading to increased mortality of remaining individuals and contributing significantly to biomass losses (Sist, *et al*., 2012). Degradation reduces the capacity of a forest to provide goods and services (FAO, Proceedings Expert Meeting on Harmonising forest-related definitions for use by various stakeholders, 22-25 January 2002), including climate change mitigation (Baccini, *et al.,* 2012; Mm, *et al.,* 2016 ; Thompson, *et al.,* 2013) The removal of forest carbon stock accompanied by combustion and mineralization of organic matter, on the contrary, leads to CO2 emissions (Matthews, *et al.,* 2014).

Over the period from 2001 to 2010, emissions resulting from forest degradation would represent a quarter of those due to deforestation (Federici, *et al.,* 2015). But a recent study suggests that degradation would contribute much more strongly, with more than two-thirds of all greenhouse gas emissions coming from tropical forests (Baccini, *et al.,* 2012). The emissions of CO2 from forest degradation are estimated to be equivalent to 1.1 Gt CO2 per year in 2011-2015 (FAO, Monitoring Deforestation and Forest Degradation: Latin American and Caribbean Forestry Commission, 2017). Sustainable forest management plans are required by law in some countries such as Brazil, limiting the density and frequency of cutting to allow regeneration, but most selective cutting does not follow a management plan and is done illegally (Richardson and Carlos, 2016). Different factors related to the organization of the territory can have an impact on the degradation of the forest: the size of the properties, the proximity of roads in good condition, towns and villages. They determine forestry and agricultural practices, accessibility (for the exploitation of ligneous resources) and the diffusion of phenomena (for fire). Anyway, in this paper, we assess the intensity of degradation according to those factors.

MATERIALS AND METHODS

Study area

The study area is located in the eastern Amazon in Pará state (Paragominas municipality). It borders five other municipalities in Pará: Ipixuna do Pará et Nova Esperança do Piriá from the north, Ulianópolis, Goianésia do Pará et Dom Eliseu in the south. It is bordered to the east by the state of Maranhão. The area of the municipality is 19,395 km². The economic activity of Paragominas is centred on services and the primary sector with family farming, entrepreneurial agriculture (mainly cattle breeding and grain crops: soybeans, maize and sorghum), logging, reforestation and bauxite mining. Paragominas is one of the municipalities in Pará with the highest agricultural and animal production (Alves *et al.,* 2014).

The transformation of the forest landscape into a livestock landscape took place mainly between 1960 and 1985. Logging intensified in the 1990s to become the

main economic activity following the beef crisis in particular. This intensification was possible thanks to the use of heavy equipment and the sector organization. The price of wood and the ease of access allowed by the road's existing infrastructures also explain this massive exploitation (Stone, 1996).Between 2004 and 2008, the federal government launched a series of decisive measures to combat deforestation in the legal Amazon. Among these measures, a "black" list of municipalities that were massively deforesting was put in place, and this municipality was on it. Paragominas launched a "Green Municipality" pact that aims to stop illegal deforestation by combining law enforcement, the creation of a local environmental police force and the promotion of an economy that no longer relies on forest cutting. The focus is on sustainable development, using sustainable forest management for the timber industry, and introducing intensive farming techniques to increase production while using less land.

Deforestation has indeed decreased considerably (Piketty, *et al.,* 2015) (Laurent, *et al.,* 2017), and Paragominas became the first municipality in the Amazon to come off the blacklist in 2010 and has been considered a model of sustainable development in the Amazon since 2008, after having been for a long time the symbol of intense deforestation.

The actions taken within the framework of this territory project have therefore been largely successful, and deforestation has been reduced to a level considered acceptable. But if deforestation has decreased considerably in medium and large properties, this has been much less the case in small family farming properties (Piketty, *et al.,* 2015), present near the city located in the northeast, northwest and southwest of the municipality. The region was also traversed by gigantic fires in 2015, resulting in severe forest degradation. Actually, the landscape of Paragominas, which has been the result of human activities for more than fifty years, is a mosaic of degraded primary forests, secondary forests, monoculture reforestation, pastures and family or entrepreneurial agriculture.

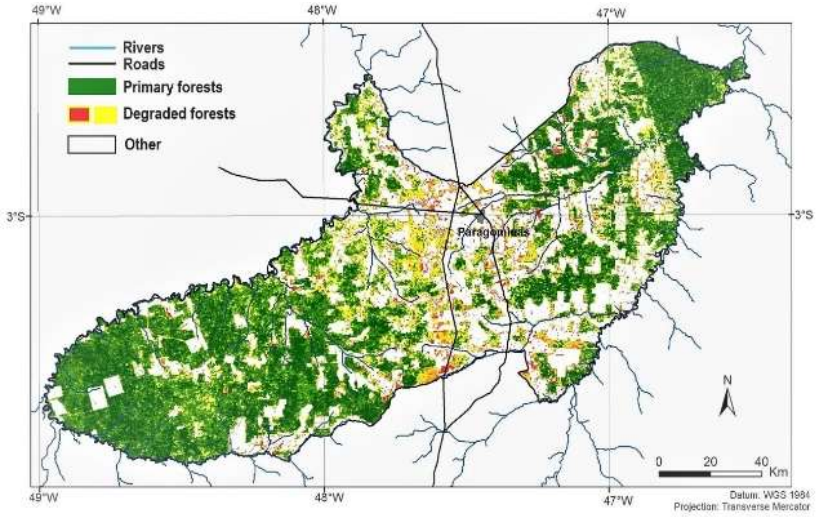


Figure (1) Map of the study area.

Data and methodology

We have analyzed the burned forest with spatial variables of the territory that can a priori have an impact on the degradation of the forest: the size of the properties, the proximity of roads, towns and villages. The 2015 forest fire data was done for (Hasan, *et al.,* 2022) Figure (2), based on the 2016 Landsat image with CLASlite and validated with INPE data. It should be noted that this analysis did not consider secondary forests. These various factors are related to the organization. They determine forestry and agricultural practices, accessibility (for the exploitation of ligneous resources) and the diffusion of phenomena (for fire).

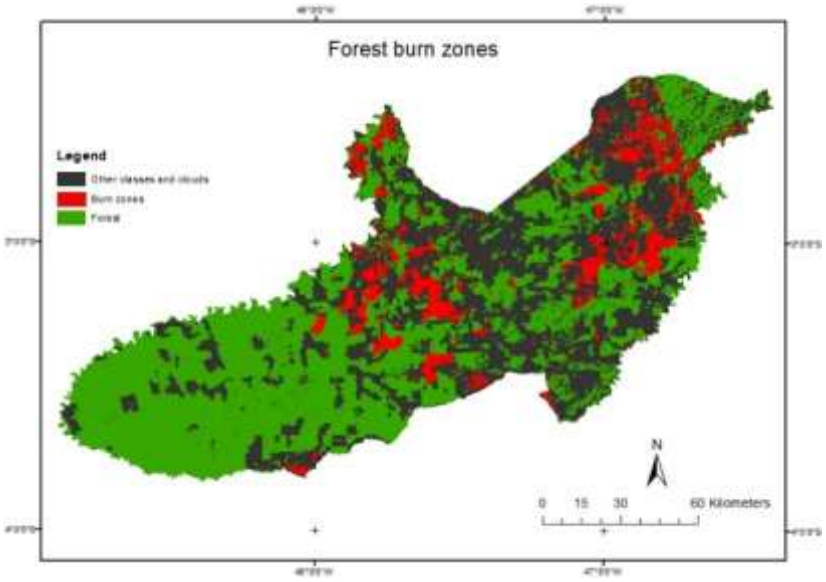


Figure (2) Forest fires data in Paragominas 2015(Hasan, *et al.* 2022)

RESULTS AND DISCUSSION

Relationship between the proportion of forest burned and the size of properties

We have analysed the relationship between the proportion of forest burned and the size of properties. The map of rural environmental cadastres (CAR) delimiting agricultural properties shapefile was used (produced by the Environment Secretariat (SEMA) of the State of Pará). We separate the properties into groups whose boundaries are multiples of "modules fiscals" of Paragominas, which means that in each group there is a different number of properties. For each group, we calculate the average proportion of forest burned in each property. The report shows a peak in the proportion of forest burned in the 55-100 ha class, so proportionally smaller properties are more affected by the fire.

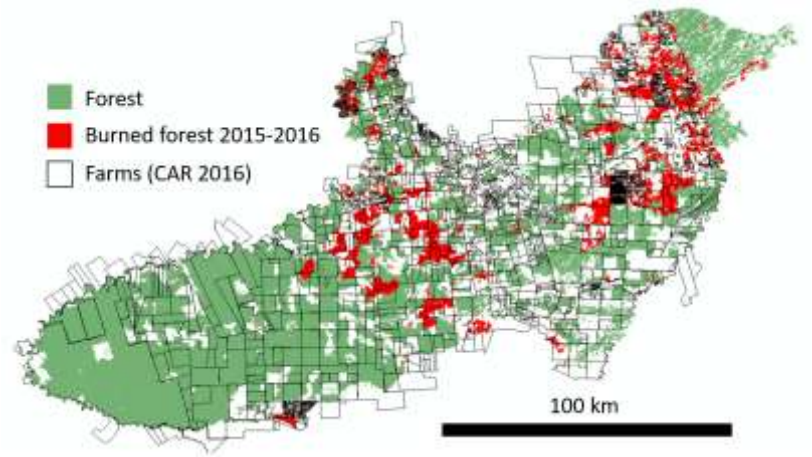
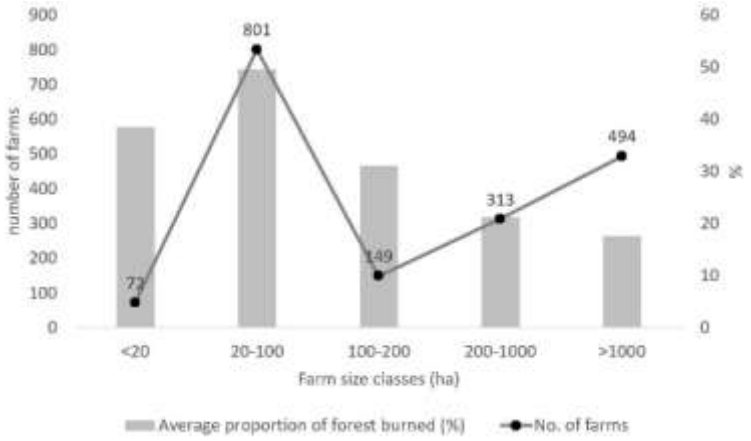


Figure (3) Map of forest burned and the size of properties.

Results show that smaller properties are generally closer to fires the small owners still practice the fire that generates fires in their forest (Anthony, *et al.* 2025). The fires are used for the preparation of land for the cultivation of cassava and maize, after the cutting of the secondary forest, as well as for cleaning degraded pastures overgrown with woody plants. The use of fire can also occur when land is invaded to keep an area clean and secure land tenure. The region suffers from the limitations of agricultural management techniques, as well as the fight against fire when it becomes harmful to populations. Our results are in line with those observed in other studies on deforestation, which were greater in areas occupied by large properties but fell more sharply than in areas with small properties (Le Tourneau, 2015).

Figure (4) : Show the relationship between the proportion of forest burned and the size of properties



The proportion of forest burned according to distance from roads

The opening of the forest in fields and pastures leads to a fragmentation of the remaining forest plots which increases the linear border and thus the risk of fire spreading in the forests (Cochrane, 2001).

This relationship shows the proportion of forest burned against each distance class of all roads. These roads were interpreted from a 2016 Landsat image; the ratio shows a higher proportion of burned forest up to about 2.5 km from these roads. Roads concentrate the flow of people and vehicles, which also increases the possibility of accidental and arson fires. Interestingly, the peak in the proportion of burned forest does not occur in the nearest class, but after 300 m, followed by a plateau up to 1.5 km, after which the proportion decreases, which may be concentrated in this area between 0.3 and 1.5 km from inhabited spaces. This location may be more favorable to the use of fire as a management technique because farmers are less exposed to control.

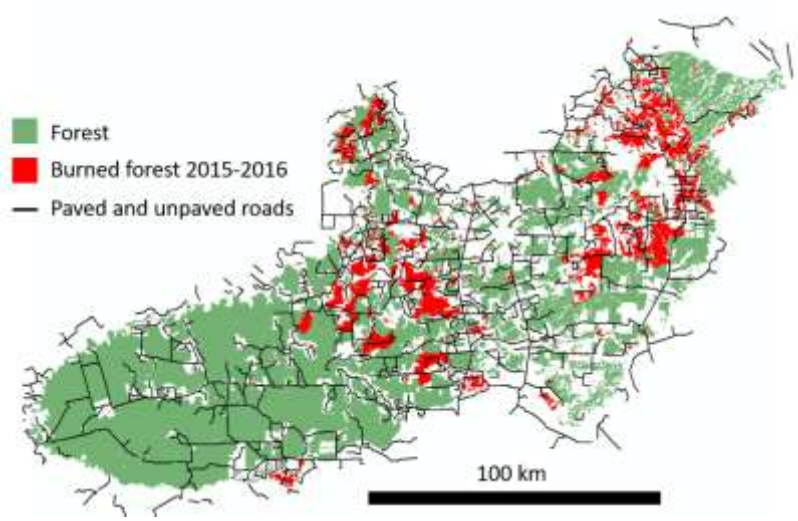


Figure (5) map of forest burned and the distance from roads.

In the case of large properties, accidental or arson fires can be important factors, so several producers make large "actors" between the roadside and their properties to avoid the burning of pastures or other uses. On the other hand, roads can serve as a fire barrier. This fact contributes to increasing the importance of the variability of the proximity of the roads with the location of the fire sources because if they function only as a fire barrier and not as a source, the graph may exhibit the opposite or different behavior. It is also important to note that in the western region of the municipality, although there are roads, there is little fire. This is mainly due to the predominance of large estates and the almost total absence of family farming. In addition, most of these roads do not have large traffic of people, only generally serving these farms, or they are internal roads of the farms.

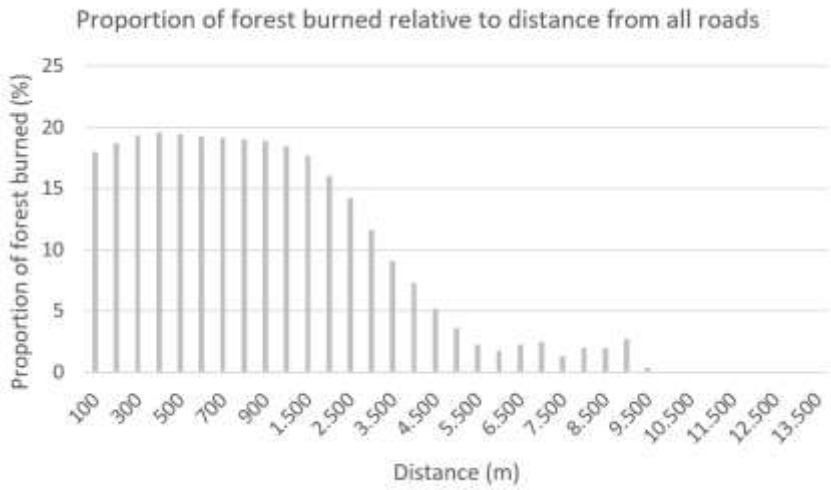


Figure (6) show the relationship between the proportion of forest burned according to distance from roads.

The proportion of forest burned according to distance from main roads

We estimated the same relationship using the distance classes of the main connecting roads between Paragominas and the villages. This relationship shows that most fires occur near these roads, especially if we only consider the settlements of Agua Suja, CAIP and Luiz Inacio. In this case, the graph does show an increase in the percentage of burned forests near these

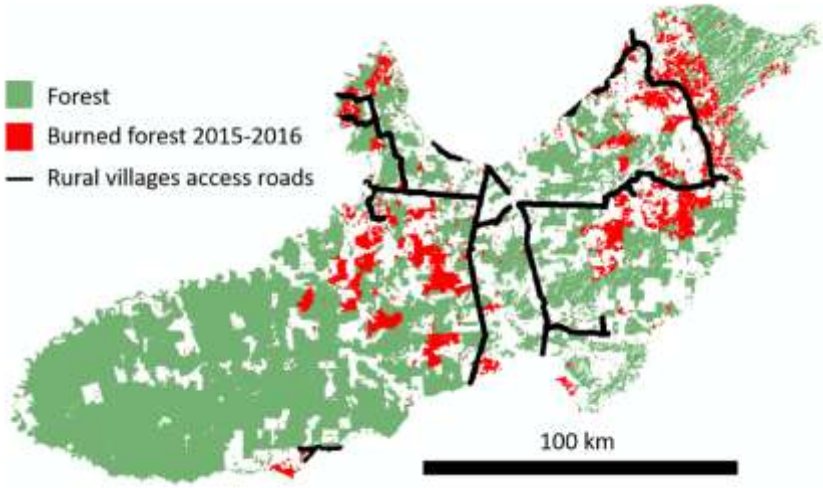


Figure (7) map of forest burned according to distance from main roads.

roads and an irregular decrease in the proportion of burned forests away from them. This may be due to the increased frequency of accidental or arson fires on these roads, given the increased flow of people and vehicles, according to distance from main roads.

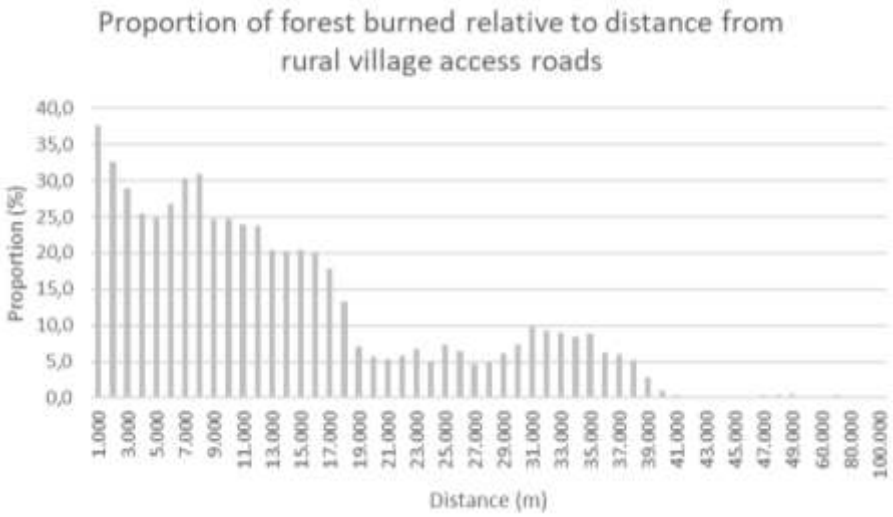


Figure (8) show the relationship between the proportion of forest burned according to distance from main roads.

The proportion of forest burned according to distance from rural villages.

We analysed the proportion of forest burned against each class of distance from villages or clusters of houses. These villages were also mainly photo-interpreted, in addition to the villages we had marked with GPS. This shows a greater proportion of burned forest between 3 and 5 km from the villages. Except for the area south of Oriente, where the most of fires are concentrated in the vicinity of these villages.

The relationship with the distance from the villages can be linked to the same relationship with the roads, ie a large part of the family plantations are located near the villages where the rural population is concentrated. There is also a greater concentration of homesteads around these villages, as in the case of Assentamentos. The peak in the proportion of burned forests does not occur in the nearest class, but between 2 and 4 km. This may be due to the lower amount of forest in the vicinity of the villages, or even to the lower exposure to taxation.

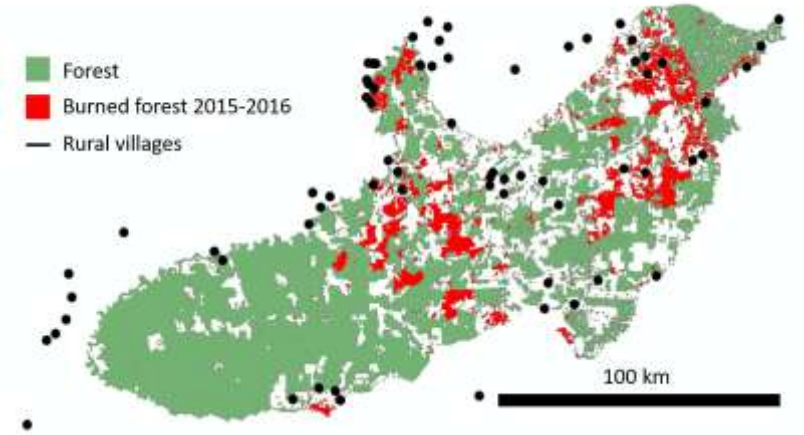


Figure (9) Map of villages or clusters in the study area.

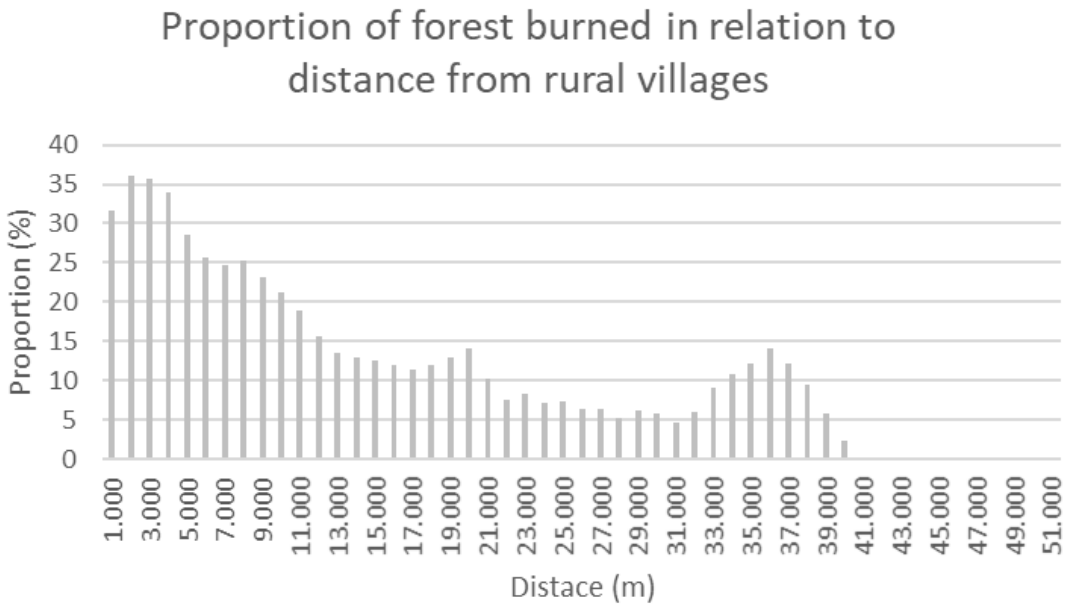


Figure (10) Show the relationship between the proportion of forest burned according to distance from rural villages.

CONCLUSIONS

The different explanatory factors taken into account in the analysis at the territory scale (size of properties, distance to roads and urban areas) show spatial links with forest fires. The spatial analysis shows schematically the forests near the city and near the main roads, belonging to the small properties, are characterized by higher to very high fires due to the intensity of human activities that exert pressures causing forest degradation such as the fragmentation of the landscape with the opening of fields and pastures, the extraction of wood resources (charcoal in the past and exploitation of timber without a management plan) and the frequency of departures of fire. The knowledge of the practices of forest fires in connection with these factors deserves to be deepened, we have put forward explanatory hypotheses without a real demonstration which would require other work by surveys.

ACKNOWLEDGMENT

The research was conducted with the financial support of the French National Research Agency (ANR), for the ECOTERA Project “Eco-efficiences et développement territorial en Amazonie brésilienne (ANR-13-AGRO-0003) and the European Union, which funded the H2020-MSCA-RISE-401 2015 ODYSSEA project. We are deeply grateful to the Cikel Verde who allowed access to their property

CONFLICT OF INTEREST

The authors declare no conflict of interest.

استخدام تقنيات الاستشعار عن بُعد لتحليل العوامل المتحكمة في حرائق الغابات في شرق الأمازون

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الخلاصة

تؤثر عوامل مختلفة مرتبطة بالأنشطة البشرية في المنطقة على تدهور الغابات، مثل مساحة الأراضي وقربها من الطرق والمدن والقرى. وتحدد هذه العوامل ممارسات الغابات والزراعة، وسهولة الوصول (لاستغلال الموارد الخشبية للغابات)، وانتشار حرائق فيها. في هذا البحث، سنركز على التقارب المكاني للمؤشرات المتعلقة بتوزيع حرائق الغابات على مستوى بلدية باراغومينس (شرق البرازيل). سيقودنا التحليل المكاني إلى تقييم دور العوامل التفسيرية في توزيع الحرائق على مستوى البلدية، وتحديد ما إذا كانت مساحة ملكية الأراضي الزراعية أو الغابية، والمسافة ما بينها وبين الطرق المعبدة، والمسافة ما بينها وبين المدن والقرى تؤثر على حرائق الغابات.

الكلمات المفتاحية: تدهور الغابات، حرائق الغابات، التحليل المكاني، منطقة الأمازون البرازيلية

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