Original Article

SPACE-TIME VARIABILITY OF VEGETATION BY ORBITAL PLATFORMS IN THE WESTERN AMAZON

VARIABILIDADE ESPAÇO-TEMPORAL DA VEGETAÇÃO ATRAVÉS DE PLATAFORMAS ORBITAIS NA AMAZÔNIA OCIDENTAL

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ABSTRACT: Percentage maps (%) of forest cover derived from the annual product MOD44B were compared with the annual deforestation data from PRODES. PRODES data were used to calibrate the MOD44B (sub-pixel-level representation of surface vegetation cover estimates globally) annual images with the aim of evaluating the annual characterization of the deforestation dynamics and forest regeneration in the municipality of Bujari - Acre, Brazil, from 2000 to 2010. The percentage rates from MODIS were divided into forest cover categories (forested and deforested areas) by means of the Mann-Kendall (MK) non-parametric test used in each category. The results were satisfactory when compared with PRODES. The analysis of MOD44B product in the municipality, during the years 2001, 2004 and 2009, shows that there was an increase of the pixel frequency in the "Extremely High" category, which indicates regeneration of the area in the municipality of Bujari. Validations *in situ* should be done primarily to the regenerate areas.

KEYWORDS: Amazon. Vegetation dynamics. Statistical analysis.

INTRODUCTION

Deforestation rates in some sites in tropical Africa, Asia and South America remained constant or increased over the past two decades, leading to the need for a more accurate assessment of forest loss (DEFRIES et al. 2002; LAMB et al., 2005). The deforestation spatial distribution in the Amazon can be associated with two interrelated factors: (i) due to the roads opening influence and appearing of development centers in the occupation process encouraged by the federal government in recent decades (ALVES et al., 1999; ALVES, 2002), (ii) land use concentration processes or expansion of new areas of deforestation associated with intensification/land abandonment e aumento de incêndios florestais e queimadas na região (ALVES et al., 2003; ALVES, 2007; CAÚLA et al., 2015).

In addition, the concentrate deforestation in some areas that are influenced by pastures and crops leads to the formation of the few remaining forests and prevent the growth of secondary vegetation (ALVES et al., 2003).

Secondary vegetation, formed by natural regeneration of deforested and abandoned areas are important in carbon sequestration (C) (NOBRE; NOBRE, 2002), assists in the creation of biodiversity corridors (BARLOW et al., 2006; STOUFFER et al., 2006), cycling and fixing of nutrients to the soil (SZOTT et al., 1999) and maintaining of the hydrological cycle in the region, integrating the coverage and change process of use of the Amazonian soil (FEARNSIDE, 2005).

In the Amazon region, the use of data obtained from orbital platforms enables high reliability studies on spatial and temporal scales in this region, regularly covering various regions of the planet, being these adjusted continuously (FREITAS et al., 2012; VILANOVA et al., 2013).

One of the sensors most widely used in large-scale studies is MODIS (*Moderate Resolution Imaging Spectroradiometer*). Its data are available since 2000, thus constituting one of the most reliable sources regarding to large-scale studies or even globally (ZHANG et al., 2009). MODIS land cover system products provide various types of input data for the monitoring of deforestation as, for example, the product MOD44B. VCF product is a global representation of the Earth's surface, and has three gradations of soil cover components: percentage of tree cover, percentage of non-vegetated area and percentage of bare area (HANSEN et. al., 2005; TOWNSHEND et al., 2001).

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This study aimed to evaluate the annual characterization of the dynamics of deforestation and forest regeneration existent in the municipality of Bujari - Acre, Brazil from 2000 to 2010, based on high-resolution data of the product MOD44B and, finally, compare the PRODES data (Deforestation Monitoring Project Satellite in the Legal Amazon) /INPE (National Institute of Spatial Research).

MATERIAL AND METHODS

Characterization and location of the study area

Bujari, in the state of Acre, is situated in 09º49'50" S and 67º57'08" W (Figure 1). It has an area of 3,035.869 Km² with 8,471 inhabitants and a population density of 2.79 inhabitants / km² (IBGE, 2014). The climate is "Aw," according to Köppen's climatic classification. The state of Acre is divided climatically into two main types of climate: humid tropical ("Af") and monsoon tropical ("Am") (Duarte, 2005).

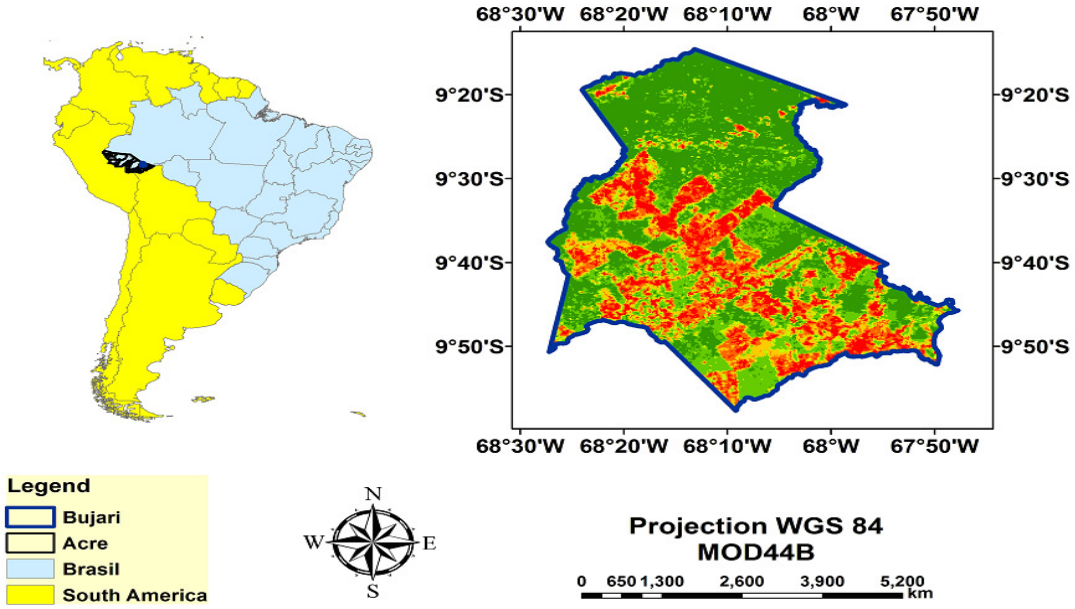


Figure 1. Geographical location of the study area and to the right MOD44B image for the year 2009.

Data processing

In this study were used 11 images annual of MOD44B product, coming from of sensor MODIS on board the orbital platform TERRA, with annual composition and spatial resolution of 250 m from 2000 to 2010. The images were acquired on April 22, 2013 coming from the NASA-EOSDIS (*National Aeronautics and Space Administration - Earth Observing System Data and Information System*), at the following website: www.reverb.echo.nasa.gov.

MODIS data were used for carrying out of pixels reading in PRODES polygons vegetation cover density, for the monitoring of deforestation dynamics and regeneration over the period. This monitoring was done in all the polygons mapped by PRODES in the municipality of Bujari, AC. The data were processed using the ArcGIS 10.1 software.

MODIS's raster images were transformed into points to facilitate the counting of the categories in percentage scale vegetation coverage found in each polygon and posterior statistical analysis. For this, we used the module Arctoolbox – Convertion Tools – From Raster – Raster to Point (Figure 2).

PRODES polygons were classified into three groups: deforestation relating to the year image, forest and deforestation. It were selected the data concerning the classification found in PRODES attribute table, and with the tool Arctoollbox – analist tools – extract – clip were developed maps with points of each group. For the classification of forest group, we selected all polygons referring to subsequent years from the year of the image. Deforestation group is related to polygons that were later added to PRODES in 2010. Este procedure was repeated for all MODIS images of the study period. The data from attribute table in the maps of each group in MODIS images from 2000 to 2010 were exported from ArcGis 10.1.

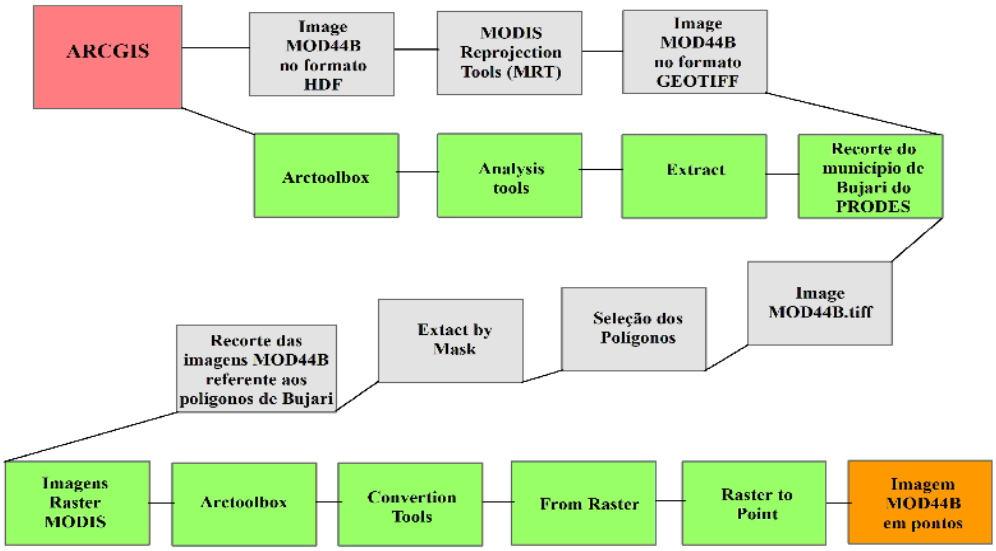


Figure 2. Flowchart related to the processing of data in ArcGIS 10.1 MOD44B software product.

According to the methodology proposed by Vilanova et al. (2013), the percentage of forest cover have been categorized: Extremely Low (0% to 5%), Very Low (5% to 17%), Moderately Low (17% to 35%), Moderately High (35% to 54%), Very High (54% to 71%) and Extremely High (71% to 89%).

Statistical analysis of the data

In order to assess change over the years and each category to the forested and deforested areas we used the Mann-Kendall non-parametric test (MK) (MANN, 1945; KENDALL, 1975). The test identifies the presence of monotonous trend without making assumptions about the properties of the data distribution. In order to perform the test a significance level (α) at 5% will be adopted. The test considers the null hypothesis (H_0) that there is no trend in the category under consideration, against the alternative hypothesis that there is a trend of increase or decrease in the said category. It used the R software version 3.2.0 (R Development Core Team, 2014).

MK test considers that, in case of stability of a time series, the succession of values occurs independently and the probability distribution should always remain the same (the series should be random).

Based on the Z statistic analysis a decision is taken to accept or reject H_0, that is, is it possible to confirm the hypothesis of data stability or reject it in favor of the alternative hypothesis (existence of trend in the data). The Z statistic signal indicates if the trend is increasing ($Z > 0$) or decreasing ($Z < 0$). In a bilateral test for trend, H0 should be rejected if the p-value found in the test statistic is less than or equal to the significance level adopted.

RESULTS AND DISCUSSION

From the division of forest coverage ratios in categories (Table 1)were performed some analysis related to land use change and driving forces operating in the deforestation process in the municipality of Bujari, AC. It was evaluated the time sequence for the years 2001, 2004, 2007 and 2010 of the MOD44B product occurred in Bujari, so as to locate the conversions of forest, deforestation and forest regeneration from the coverage ratios during this period (Figure 3). The category with the highest percentage rate of forest cover was Extremely High (65.1%, 2001) and in the year 2010 (35.0%), a reduction of 30%. This result is corroborated by the MK non-parametric test, which showed a significant annual decrease of 2.36 in this category.

The years 2001, 2004 and 2009 in the total analysis of the MOD44B product in the municipality, there was an increase in the pixels frequency of the Extremely High category, which indicates regeneration of the municipal area. Comparing the years 2008 and 2009, the frequencies of the Extremely High categories were 36.6% and 47.9% respectively (Table 1).

Table 1. Pixels frequency in percentage (%) of the forest cover categories obtained from MODIS product for the municipality of Bujari, AC, in the period 2000 – 2010.

Categories	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Extremely Low	0.26	0.17	0.01	0.24	0.02	0.02	0.02	0.02	0.01	0.00	0.04
Very Low	13.3	10.5	12.5	13.7	14.3	10.4	12.1	12.8	10.8	1.8	6.6
Moderately Low	10.2	11.7	10.6	11.3	12.4	17.3	16.8	15.8	18.5	22.0	20.3
Moderately High	6.4	8.9	7.2	9.9	6.4	9.2	9.3	13.3	14.0	10.5	13.1
Very High	16.0	3.5	12.8	17.3	10.3	11.5	18.4	15.6	20.0	17.9	24.8
Extremely High	53.8	65.1	57.0	47.5	56.7	51.5	43.3	42.7	36.6	47.9	35.0

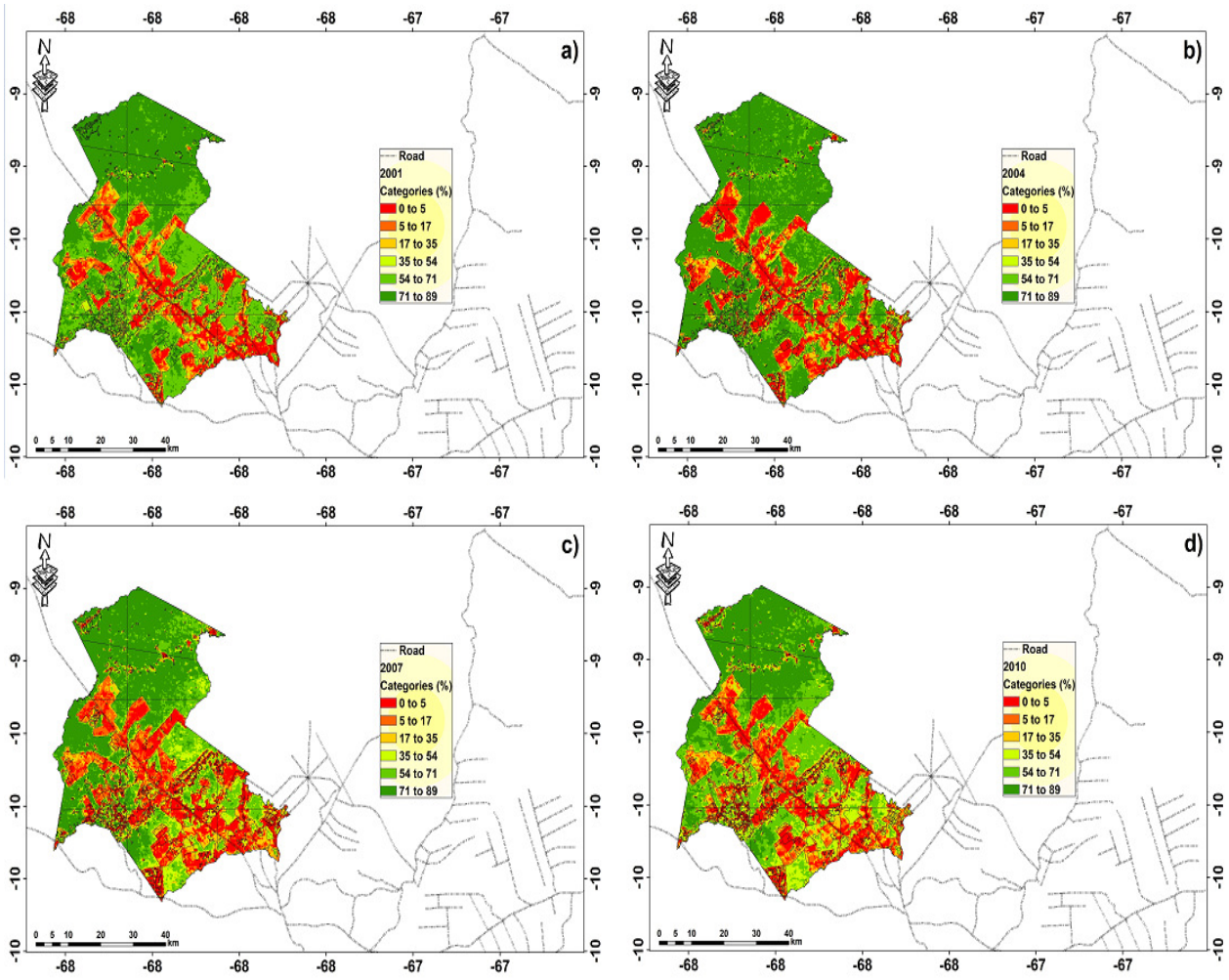


Figure 3. Percentage maps (%) of forest cover based on MOD44B product categories from 2001 (a) 2004 (b) 2007 (c) to 2010 (d) of the municipality of Bujari, AC.

This behavior of the spatial distribution of forest cover categories in the years 2007 to 2009 can be explained according to the PRODES data, where it was calculated that the years 2007 and 2008 had an lowest deforestation increment in the period, with only 9 km² (Figure 4). This possible regeneration of the area can be explained by the reduction of large-scale disturbances, since the regeneration dynamics is strongly influenced by endogenous factors (vegetation structure and interaction among species)

(AUGSPURGER, 1984). In addition, the less intensive use of land in the first years after deforestation and the best state of the seed bank (UHL and CLARK, 1983) may explain the higher proportion of regenerated area in 2007 and 2008 compared to previous years in the studied region.

These results found for the years 2007 and 2008 are in agreement with the conclusions found by Caldato et al. (2009), who recommend, because of large seasonality in the production and seed accumulation in a period exceeding one year in tropical forests. These authors also emphasize that the study in not changed wild areas is essential to have an understanding of these complex structures, placing greater emphasis on research focusing on the environmental behavior of the beings in the ecosystem.

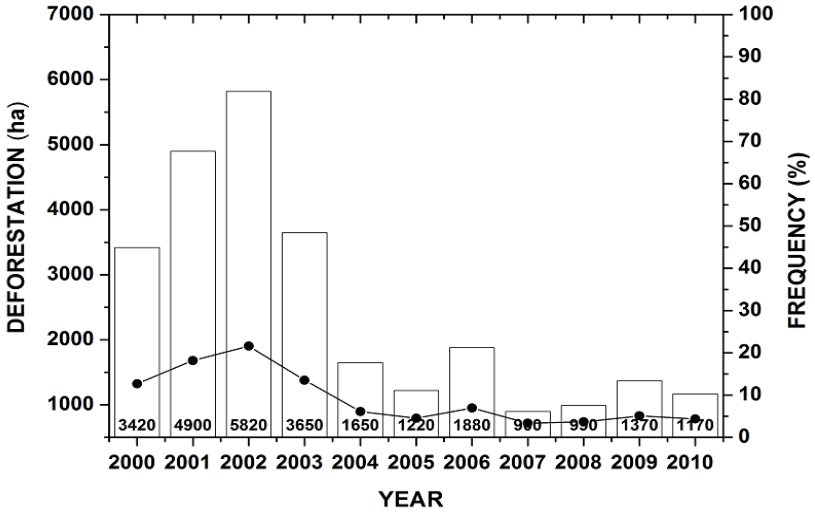


Figure 4. Increase DEFORESTATION and frequency (%) based on PRODES- INPE system in hectare (ha). Source: Bank of PRODES data.

In the categories namely Very High and Moderately High there is a significant increase of 21.3% and 4.2% for the same period. However, only in category Very High this increase is significant at 5% level (Table 2). With the reduction of percentage rates in the high categories, followed by an increase in low percentage rates, it is verified the replacement of percentage rates in the high categories over 10 years and consequently decrease of forest cover density in Bujari.

Table 2. Mann-Kendall test applied to the categories of forest and deforestation in the municipality of Bujari, AC, in the period 2000 – 2010.

Categories	Deforestation		Forest	
	Inclination	p-value	Inclination	p-value
Very Low	0.00	0.63	0.00	1.00
Moderately Low	1.82	0.00*	0.17	0.02*
Moderately High	3.12	0.01*	0.48	0.06
Very High	0.91	0.31	1.97	0.04*
Extremely High	-6.32	0.00*	-2.36	0.01*

According to the data obtained from PRODES (Figure 5), the deforestation in Bujari gradually increased in the categories Moderately Low and High, especially in 2005, compared to other categories over the period, by the MK test this was of 1.82 and 3.12, respectively (Table 2). In comparison with the distribution of the pixels frequency in each forest cover category does not confirm the results on the reduction of forest cover category Extremely High annual.

The reduction is due to the land use process in the state of Acre that occurred in the 1980's, from public colonization policies with highway construction and land acquisition incentives for business groups (domestic and foreign) – (MARGULIS, 2003; VILANOVA et al, 2013).

According to Fearnside (2005), abandoned pasture areas give rise to secondary vegetation with slower regeneration and lower biomass accumulation, compared to the secondary vegetation of itinerant agriculture. Thus, the deforestation process occurs faster than the forest resilience capacity in the region.

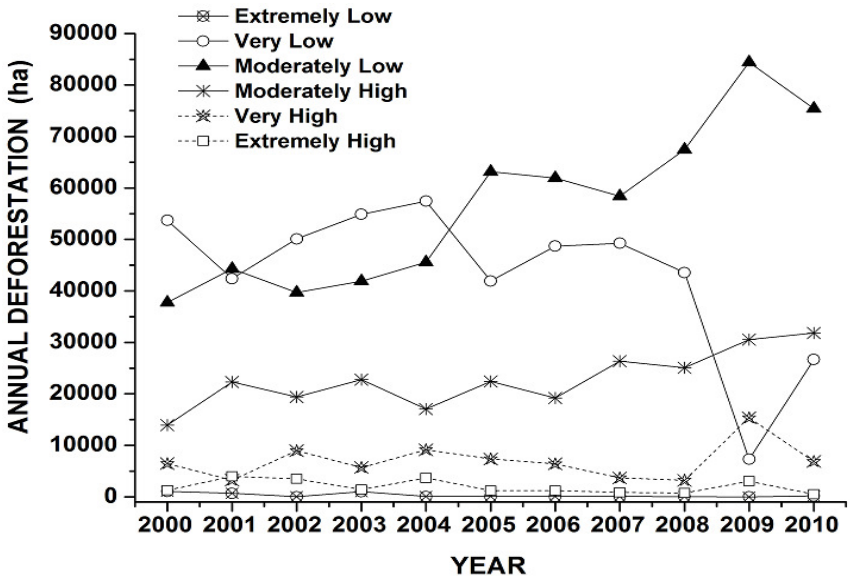


Figure 5. Distribution of annual deforestation in hectare (ha) according to PRODES system. Source: Bank of PRODES data.

CONCLUSIONS

Spatial and temporal analysis of the pixels distribution divided into categories of forest cover percentage in the images can explain the deforestation and regeneration dynamics of the study area, based on the raw data calculated by the PRODES system.

The reduction of the size of deforested increments from the PRODES in the region, when compared with images from the MODIS product, shows possible forest regeneration in the municipality of Bujari, AC, over the period. The raw data from the PRODES system does not infer on regenerated areas which may overestimate the total deforestation values.

In the statistical analyzes, some categories showed no significant variability among the years evaluated. However, the high pixels frequency with the spatial analysis, these categories can reveal possible relationship with the PRODES data.

It is noteworthy that the frequency analysis should be done together with the visual classification of maps. Validations *in situ*, especially for the regenerated areas should be performed.

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RESUMO: Mapas percentuais (%) de cobertura florestal provenientes do produto anual MOD44B foram comparados com dados anuais de desflorestamento anual PRODES. Os dados do PRODES foram utilizados para calibrar as imagens anuais MOD44B (representação sub-pixel-nível de estimativas de cobertura de vegetação de superfície a nível mundial) com o objetivo de avaliar a caracterização anual da dinâmica de desmatamento e regeneração de florestas no município de Bujari – Acre, Brasil entre 2000 a 2010. Os índices percentuais do MODIS foram divididos em categorias de cobertura florestal (áreas desflorestadas e florestadas) por meio do teste não-paramétrico Mann-Kendall (MK) em cada categoria. Os resultados foram satisfatórios quando comparados com PRODES. Observa-se um aumento da frequência de pixels da categoria Extremamente Alta nos de 2001, 2004 e 2009 na análise total do produto MOD44B no município, o que indica a regeneração da área do município de Bujari. Devem ser realizadas validações *in situ* principalmente para áreas regeneradas.

PALAVRAS-CHAVE: Amazônia. Dinâmica da vegetação. Análise estatística.

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