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Trend in hydrological series and land use changes in a tropical basin at Northeast Brazil

Tendência em séries hidrológicas e de mudanças no uso e cobertura da terra em uma bacia tropical do Nordeste do Brasil

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ABSTRACT

Flow is one of the hydrological variables of greatest interest due to its connection with water availability and its multiple uses. However, in recent years this resource has been threatened by intense land use and climate change, affecting patterns previously considered to be stationary. The goal of this study was to evaluate trends in changes of patterns of flow, precipitation, and land use in a basin located in the Brazilian Cerrado. 33 years of rainfall, fluviometric, and land use data were used, covering the period of 1985 to 2018 on an annual scale. Mann-Kendall and Sen Slope's nonparametric test was applied to evaluate the trends in temporal series, as well as the Spearman Rho and Pettit, which were used to analyze the correlations between variables and detect the point of change in the series, respectively. The results show statistically significant trends in flow reduction over time. At the same time, a considerable reduction in natural areas occurred, with an increase of +750% in agricultural areas. The results also show that although a tendency to reduce precipitation was detected, its magnitude was not significant, with land use changes being the main factor for the negative changes in the flow of the Rio Grande tributary.

Keywords: stacionariety; flow; nonparametric tests; Rio Grande river.

RESUMO

A vazão é umas das variáveis hidrológicas de maior interesse por sua importância econômica e ligação direta com a disponibilidade para os usos múltiplos da água. Nos últimos anos, no entanto, esse recurso tem sido ameaçado pelas grandes alterações no uso e ocupação do solo e pelas mudanças climáticas, com alterações nos padrões antes tido como estacionários. O objetivo deste estudo foi avaliar as tendências de mudança nos padrões de vazão, precipitação e de uso e ocupação do solo e sua correlação ao longo do tempo na bacia do Alto Rio Grande. Foram utilizados 33 anos de dados pluviométricos, fluviométricos e mapas de uso e ocupação do solo para o período de 1985–2018, em escala anual. Para indicar a presença ou não tendências nas séries históricas, foi aplicado o teste não paramétrico de Mann-Kendall; para avaliar a magnitude dessas tendências, foi utilizado o coeficiente Sen's Slope, além dos testes de Spearman Rho e Pettitt para correlacionar as variáveis e detectar o ponto de mudança nas séries, respectivamente. Os resultados inferem tendências de redução no posto fluviométrico verificado, estatisticamente significante a 5% de probabilidade. Concomitantemente, houve considerável redução das áreas naturais e ascensão de +750% das áreas agrícolas. Os resultados mostram ainda que, embora tenha sido detectada uma tendência de redução na precipitação, sua magnitude não foi relevante quando relacionada à vazão, sendo as mudanças do uso e ocupação do solo o principal fator para as mudanças negativas na vazão do afluente Rio Grande.

Palavras-chave: estacionariedade; vazão; testes não paramétricos; rio Rio Grande.

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Introduction

Recently, trend analysis in hydrological series has received attention in the scientific community (Rosin et al., 2015; Pousa et al., 2019; Salehi et al., 2020; Alifujiang et al., 2021). This concern has been largely attributed to climate change, due to its impact on the hydrological cycle such as pandemics, low food productivity, reduced availability and quality of water, imbalance in ecosystems such as loss and fragmentation of habitats inducing the loss of biodiversity (Campbell et al., 2016; Das et al., 2018; Sharma et al., 2018; Moraci et al., 2020).

According to Poorheydari et al. (2020), although water availability is attributed to climate change, factors such as land use changes are among the most relevant factors for variations in the hydrological behavior of the basin. Changes occurring in a region influenced by the rainfall regime can affect the management of water resources, as well as the availability of drinking water and food production, which can cause conflicts (Hu et al., 2017). Although this scenario is associated to climate change and rainfall patterns, factors such as land use changes may also be connected (Lamichhane and Shakya, 2019).

Land use changes are among the most relevant factors behind alterations in the hydrological behavior of the basin. Since changes in previously natural surfaces cause alterations in the components of the water balance, they create an increase/decrease in evapotranspiration, surface runoff, and consequently, in the recharge of confined waters, infiltration and interception (Medeiros et al., 2019; Poorheydari et al., 2020).

These changes affect the water cycle beyond the river flows, causing a series previously considered stationary to become non-stationary (Jehanzaib et al., 2020). When a hydrological series does not reproduce the same statistical parameters (mean and constant variance) over time, it is considered non-stationary (Naghettini and Pinto, 2007). However, identifying the changing patterns in a hydro-meteorological series at the local level is complex, due to several active factors that can contribute, jointly or separately, for variations in stationarity patterns (Milly et al., 2008), in addition to the specific characteristics of the region, such as the size of the basins (Chagas and Chaffe, 2018).

Given these facts, it is necessary to understand the impact of climate change on the hydrology, as well as evaluate trends and their magnitude in the temporal series. Many researchers have used classic trend detection models, such as the Mann-Kendall test; for correlating the magnitude of trends using the Rho Spearman test; and the Pettitt test, widely used for the analysis of abrupt changes in a hydroclimatic series (Tamagnone et al., 2019; Ferreira et al., 2020; Mirdashtvan et al., 2020; Salehi et al., 2020). These studies report urbanization, population growth, and the rise of agricultural land as the main factor behind the changes in the statistical patterns of the hydro climatological series.

Western Bahia is one of the most active agricultural frontiers in Brazil. In the last decades, the region has developed an extreme extension of agricultural activities and pastures, a process that occurred in an accelerated way under modern bases with permanent and mechanized irrigation mainly for the cultivation of beans, soybeans, cotton, and corn (Santos et al., 2018). Due to the intense agricultural development combined with the constant conflicts between multiple uses of water, this region may be suffering the effects of stationarity changes in the hydrological series.

The authors Nascimento and Santos (2019) also report the accelerated growth of +100% in agricultural areas in the Fêmeas River basin for irrigated agriculture and +100% for rainfed agriculture, mainly stimulated by governmental actions, in addition to the region's physical characteristics, such as flat relief and rainfall, which can reach 1,265 mm/year.

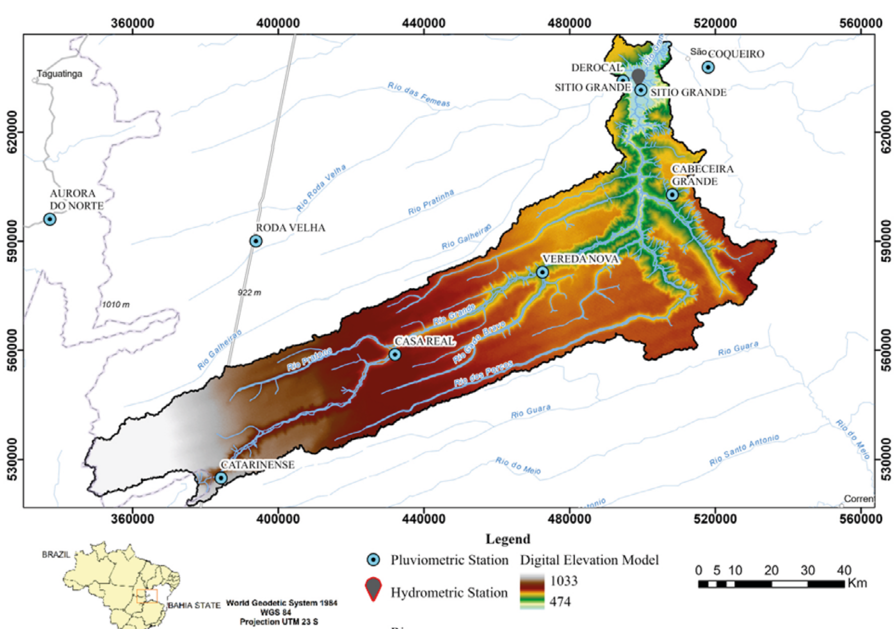

Figure 1 – Location of the study area.

This accelerated rise in agricultural areas to the detriment of deforestation can cause future damage to the water supply and the maintenance of local agriculture, since conflicts over supply and demand are already a reality. These factors raise the importance of studying the possible impacts on the statistical patterns of the hydrological series in the region for better management of water resources.

Given the reasons above, the current work aims to evaluate trends in changes in patterns of flow, precipitation, and land use, as well as their correlation over time in the Upper Rio Grande basin.

Materials and Methods

Study area

The study area (Figure 1) comprises a sub-basin of the Alto Rio Grande, totaling 5,193 km². The main river is one of the tributaries of the Rio Grande, a watercourse in Bahia, located in the northeastern portion of the state. It starts in the Serra Geral in Goiás and runs through the city of São Desiderio until it flows into the mouth of the São Francisco River.

According to the Koppen classification, the region's climate is classified as Aw-tropical with summer rains (Beck et al., 2018) with an average annual temperature of 22.3°C, a minimum of 15°C and a maximum of 40.9°C. The average annual precipitation corresponds to 1,100 mm per year and relative air humidity ranges between 45 and 79%. The region is located in one of the most extensive and important aquifers in Brazil, the Urucuia Aquifer System (SAU), being of great importance in the regulation of the rivers in the São Francisco River basin. This aquifer is responsible for the perpetuity of water bodies in the region, especially in the dry periods corresponding to the months of June to August (Gonçalves et al., 2018).

Data acquisition and processing

Fluviometric data

The fluviometric daily data were used to calculate average rainfall and were acquired from the online platform Hidroweb, made available by the National Water Agency (ANA, 2020). The monitoring station (code 46415000) is located at the lowest altitudes in the region (Figure 1). The monitoring period for the station is 1977-2020, using 33 years of measured data (1985-2018).

Rainfall data

The rainfall data were acquired from ANA's hydro-meteorological network and corresponds to 7 stations within the perimeter of the study area as well as 3 more stations to fill in rainfall gaps. The data is described in Table 1 and serve as a basis for calculating the annual average rainfall volume in the region.

The analyzed period corresponds to the same one used for the flow data (1985-2018). To fill the gaps, the regional weighting method was used based on the average precipitation of neighboring stations, described in Equation 1:

$$P_Y = \frac{P_{Ym}}{3}\left(\frac{P_{X_1}}{P_{Xm_1}} + \frac{P_{X_2}}{P_{Xm_2}} + \frac{P_{X_3}}{P_{Xm_3}}\right) \quad (1)$$

In which:

PY = Precipitation of the post to be corrected;

PYm = Average precipitation of the post Y;

Px1 to Px3 –= precipitation of posts x1 to x3;

PMx1 to PMx3 = average precipitation of posts x1 to x3.

This method is widely disseminated in the literature, being used by several authors (França et al., 2019; Ferreira et al., 2020; Fistarol and Santos, 2020; Junqueira et al., 2020), mainly for trend statistical analysis, since short period series can signal non-stationarity, when in fact they are natural fluctuations of the analyzed hydrological series. Of the seven stations that make up the basin perimeter, four had faults: Catarinense, Casa Real, Cabeceira Grande, and Vereda Nova during 1985 to 2000. These gaps were filled by the regional weighting method, whose filling scale was the monthly average data, with the aid of three other rainfall stations. These stations were incorporated into the study with the purpose of filling gaps (according to Table 1), as they contain a complete historical series and are close to the stations with missing data.

Table 1 – Location of rainfall stations.

Name	Code	Latitude	Longitude	Elevation
Sitio Grande	1245007	-12.43	-45.08	507
Catarinense	1346010	-13.28	-46.02	867
Casa Real	1345002	-13.01	-45.63	751
Cabeceira Grande	1245016	-12.66	-45.01	657
Sitio Grande	1245001	-12.43	-45.08	527
Derocal	1245005	-12.41	-45.12	511
Vereda Nova	1245030	-12.83	-45.30	690
Stations used to fill in faults				
Aurora do Norte	1246001	-12.71	-46.40	464
Roda Velha	1245015	-12.76	-45.94	820
Fazenda Coqueiro	1244019	-12.38	-44.93	607

Land use mapping

To evaluate land use changes, 33 maps covering the period of 1985 to2018 were used, available on the Annual Mapping Project for Land Use in Brazil Mapbiomas online platform, collection 4. The land use mapping was carried out through pixel-by-pixel classification of mosaics of Landsat images (spatial resolution of 30 m). Each mosaic was prepared according to the different scenes contained in each card and calculated from the median, pixel by pixel within a time interval. The general accuracy of the maps used was 82.9%, allocation disagreement was 12.5%, and area disagreement 4.7% (MapBiomas, 2020).

The mapbiomas were inserted in ArcMap 10.5, where they were redesigned for UTM datum SIRGAS 2000 and cut according to the morphometric characteristics of the basin as area and perimeter. The land use classes were reclassified into 5 categories:

- Forest: tree species, with the formation of a continuous canopy;
- Savannah: areas with a predominance of tree and shrub species, spread over a grassy substrate, without the formation of a continuous canopy;
- Grassla–d: the predominance of herbaceous species and some shrubs, without the occurrence of trees in the landscape;
- Agriculture: area for the cultivation of crops, mainly grains such as soybean, corn, and cotton;
- Past: pasture areas for livestock, dirty fields;
- Urban areas: man-made areas, urban infrastructure, constructions, access roads, and buildings.

Statistical tests

The statistical tests used in this study are described in the sections below. The significance level $\alpha = 0.05$ (5% probability) was adopted for all three applied methods. If the probability (p) of the test is $p > \alpha$, the test is statistically insignificant. All tests were processed in *software R.*

Mann-Kendall test

The Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975) is a non-parametric test used to detect the presence or absence of trends in historical series. The null hypothesis (H0) points to the absence of a trend over time, against the Alternative Hypothesis (HA) that there are increasing or decreasing trends. It is a widespread test in the literature, being used for the analysis of hydro-meteorological series (Karmeshu, 2012; Ahmad et al., 2015; Mudbhatkal et al., 2017; Alifujiang et al., 2021). This test is recommended by the World Meteorological Organization for detecting long-term trends in natural series (Liang et al., 2011).

The value of S is described by Equation 2 and calculated from the signs of the difference sgn, pair by pair, involving all values of the series (xi) and the values they will assume in the future (xk)In which the time series x_i proceeding from $i = 1, 2, ..., n - 1$ and x_k coming from $k = i + 1, ..., n$ is described in Equation 3.

$$S = \sum_{i=1}^{n-1} \sum_{k=t+1}^{n} sgn(x_k - x_i) \tag{2}$$

$$sgn\ (\theta) = \begin{Bmatrix} +1, \theta > 0 \\ 0, \theta = 0 \\ -1, \theta < 0 \end{Bmatrix} \tag{3}$$

Where:

xj = the estimated sequence of values'

n and the length of the time series and the sign (xi - xj) is equal to -1 for (xi - xj) < 0, 0 for (xi - xj) = 0, and 1 for (xi - xj) > 0 (Equation 4).

$$Z_c = \begin{Bmatrix} \dfrac{S-1}{\sqrt{var(S)}}, & S > 0 \\ 0\ \ , & S = 0 \\ \dfrac{S+1}{\sqrt{var(S)}}, & S < 0 \end{Bmatrix} \tag{4}$$

Z_c is the statistical test and when $|Z_c| > Z_{1-a/2}$, which $Z_{1-a/2}$ are the standardized normal variables and α is the level of significance to the test, *Ho* will be rejected. The magnitude of the trend is described in Equation 5:

$$\beta = Median\left(\frac{x_i - x_j}{i - j}\right), \forall_j < i \tag{5}$$

In which:

$1 < j < i < n$.

The positive value of β indicates an increasing trend, while the value of β negative indicates a decreasing trend.

Sen's slope

Although effective in detecting trends in hydro-meteorological series, the Mann-Kendall test does not represent the magnitude of the trend (Moreira and Naghettini, 2016; Salehi et al., 2020).

Therefore, the model proposed by Sen (1968) was used in this study as an aid to the Mann-Kendall test to estimate the slope or change rate and it is described by Equation 6:

$$Q_{ij} = \left(\frac{x_j - x_i}{j - i}\right), com\ i < j \tag{6}$$

In which:

X_i e X_j = the variable values in years *I* e *j* in question.

The values of Q vary positively or negatively, as positive values indicate the magnitude of the increasing trend, and the Sen Slope indicator is the value of this rate of change, while negative values represent the magnitude of the decreasing trend. The Sen's slope estimator is the median of N values of *Qij* (Tao et al., 2014). The Sen Slope's non-parametric test applied in this study infers that the null hypothesis (H0) affirms the absence of the rate of variation of increasing or decreasing trend in the hydroclimatic series, while the alternative hypothesis infers the rate of variation in the presence of trends in the series.

Pettit test

The Pettit test (Pettitt, 1979) uses a version of the Mann-Whitney test and serves to complement the Mann-Kendall and Sen's slope tests. Pettit's inference is non-parametric and checks whether two samples belong to the same population. The statistical test counts the number of times that the first sample exceeds the second, therefore, the result is what defines whether two samples are statistically different. Thus, this test was used in order to identify points of abrupt changes in the historical flow series, precipitation, and land use. The null hypothesis of the Pettit test (H0) admits the absence of a turning point in the historical series while the alternative hypothesis admits the presence.

This arbitrary point is given by the Equations 7, 8 and 9:

$$K_T = max_{1 \le t \le T} \left| U_{t,T} \right| \quad (7)$$

In which:

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} sgn\left(X_i - X_j\right) \quad (8)$$

In which:

$$sgn\ (X) = \begin{cases} 1\ se\ x > 0 \\ 0\ se\ x = 0 \\ -1\ se\ x < 0 \end{cases} \quad (9)$$

Therefore, the statistical test is calculated for values of 1 ≤ t ≤ T, and *KT* statistics of the test is the maximum absolute value of *Ut*, *T*. Thus, the test reports the presence or absence of two samples in the same population, indicating the location in the time series of the turning point (Penereiro and Ferreira, 2012). When reporting the absence of change, the hypothesis is null.

The critical value to be adopted is given by the Equation 10:

$$P \cong 2\ exp\left(\frac{-6K_T^2}{T^3 + T^2}\right) \quad (10)$$

In which:
P = the level of significance;
KT = the critical value;
T = the number of years in the historical series.

Rho Speaman test

The Spearman test was used to evaluate the correlation between two quantitative variables (Zhang et al., 2015). In this test, the proposition is based on the fact that the time series data are independent and equally distributed. The null hypothesis (H0) reports the lack of a trend over time and in contrast, the alternative hypothesis (HA) points to increasing or decreasing trends in the series (Kale and Sönmez, 2018). It is described by Equations 11 and 12.

$$D_{sr} = 1 - \frac{6\sum_{i=1}^{n}(R_i - i)^2}{n(n^2-1)} \quad (11)$$

$$D_{sr} = D_{sr}\sqrt{\frac{n-2}{1-D_{sr}^2}} \quad (12)$$

Where:
Ri = the classification of the observations of *i*;
n = the size of the historical series.

The results range between 1 and -1. The positive ρ value suggests an increasing trend while the negative value suggests a negative trend. In this study, the flow was the variable used as a parameter for the correlation. Therefore, value 1 was accepted for this data, which was used in the relationship between land use x flow and precipitation x flow. The variables of land use and precipitation can vary negatively or positively,either decreasing or increasing impact on the flow, respectively.

Results and Discussion

Trend in the series of annual average flow

The historical series of average annual flows in the Rio Grande affluent during the measured period is shown in Figure 2.

A downward trend is noticeable in the flow data, with the lowest flow values detected in recent years. This behavior indicates possible non-stationarity in the historical series of flow through the strong tendency to decline, indicated by the trend line. The results of the statistical tests for analysis of stationarity are shown in Table 2. The results of Mann-Kendall tests applied to the flow variable showed significance at 5% of probability. The null hypothesis was rejected, and the series cannot be considered stationary. The value of tau (-0.74) infers a downward trend in the fluviometric series, which is confirmed by the magnitude of the decline in the Sen Slope test (-0.59).

Change point of the average annual flow

After identifying a decreasing trend in the flow series, the Pettit test was applied to detect the breaking point (change) of the temporal

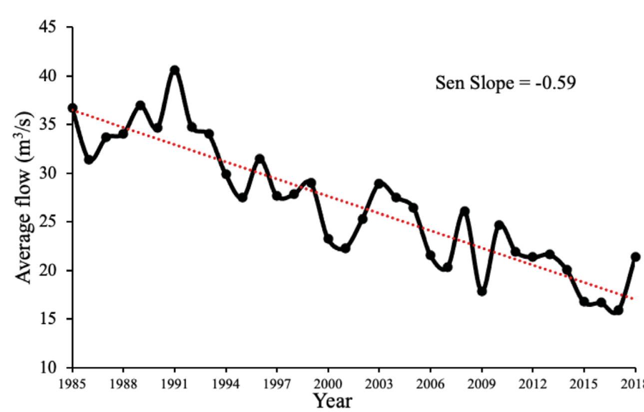

Figure 2 – Average annual flow for the Sítio Grande monitoring station.

Table 2 – Results of Pettitt change-point analysis, Kendall's tau and Sen's slope tests for streamflow, precipitation and land use classes (annual).

Parameter	Pettitt Change Year	*p* for change point	Mann–Kendall test		*Sen Slope*
			tau	*p*	
Streamflow	1999	2.288e-05	-0.74	7.612e-10	-0.59
Precipitation[a]	2011	0.1049	-0.27	0.02074	-11.74
Agriculture	2001	9.102e-06	0.96	2.698e-10	51.69
Past	1998	8.356e-06	0.84	9.369e-16	5.132
Urban areas	1999	1.786e-05	0.82	2.113e-12	0.0008
Forest	2002	0.0001203	-0.76	1.242e-13	-1.48
Savanna	2002	8.356e-06	-0.89	1.517e-15	-24.87
Grassland	2001	1.175e-05	-0.96	8.075e-10	-31.52

[a]Average annual precipitation for the entire basin.

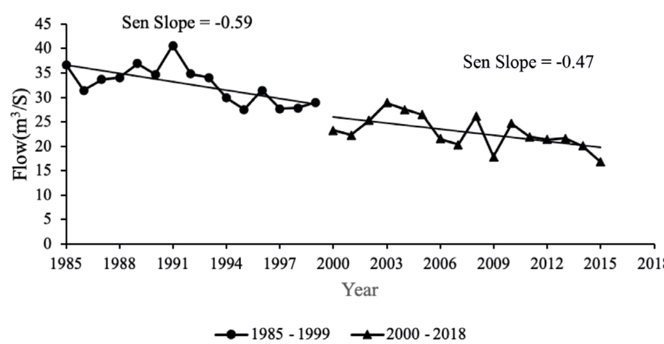

Figure 3 – Change point in the average annual flow of the Sítio Grande monitoring section.

series. The test showed significance at 5% probability and indicates the point of change within the series in 1999. According to the results, it is possible to verify two different hydrologic periods (Figure 3).

After the separation of the hydrological periods, it is observed that the average annual flow was 32.69 m^3/s during the 1985-1999 period and in the second period, it becomes 22.11 m^3/s, a reduction of 32.33% in the average annual flow. The negative trend in the reduction of the flow is statistically proven in the MK test and the conflicts that emerge in the area reinforce the need to investigate the possible causes of this reduction.

Trends in the precipitation series

The results of the MK test for rainfall data showed a decreasing and statistically significant trend. Although the null hypothesis is rejected, with the inference that a decreasing trend was detected, this trend has little magnitude (tau = -0.27), also confirmed by the Sen Slope test (-11.75).

The visual analysis of the graphics presented in Figure 4, shows the declining behavior in the annual average of rainfall in four seasons: Vereda Nova (1245030), Casa Real (1345002), Sítio Grande (1245007), and Fazenda Catarinense (1346010). The trend line in red, declining from right to left, indicates a decreasing behavior, although without much inclination magnitude. The magnitude of the changes by season was analyzed separately to better understand the precipitation decline trends. The MK and Sen slope tests were applied for the 4 seasons and are described in Table 3.

The tests were applied to understand the level of changes in these four seasons, and although this trend is evident, its magnitude does not reach variations of 20 mm/year. The spatial distribution of the rainfall regime was shown in Figure 5A and the magnitude of the changes in (mm/year) in Figure 5B.

The average data of pluviometry in the Rio das Fêmeas sub-basin ranges from 970 mm to 1,200 mm and the trends of change were detected throughout the entire basin, from the head to the executory, the biggest change occurring in the headland region (-14.40 mm/year).

Land use changes

Authors report that one of the main factors that can lead to non-stationarity in hydrological series are land use changes (Bayazit, 2015; Deb et al., 2019). The results from the analysis of the spatial-temporal variation of land use in Rio das Fêmeas (Figure 6), culminated in a considerable alteration on the landscape in the last 34 years of study.

Between the period of 1985 to 2018, there was an increase of 635.86% in anthropized areas (pasture, agriculture, and urban areas). The changes and percentages are described in Table 4. The accelerated growth in the region was driven by public policies between the late 1980s and early 1990s, especially in agricultural areas. The federal and state government made agriculture extensive in the region, through the concession of lands prone to low-cost agriculture, making it promising from an economic point of view and attractive to farmers across the country (Oliveira and Vieira, 2018).

This immigration occurred not only in the western region of Bahia but also in the central-western region of the country, which was the locus for the expansion of agriculture and the creation of a frontier in the country, known as MATOPIBA – an acronym for Maranhão, Tocantins, Piauí e Bahia, considered by many to be a newly mechanized northeast (Reis et al., 2020).

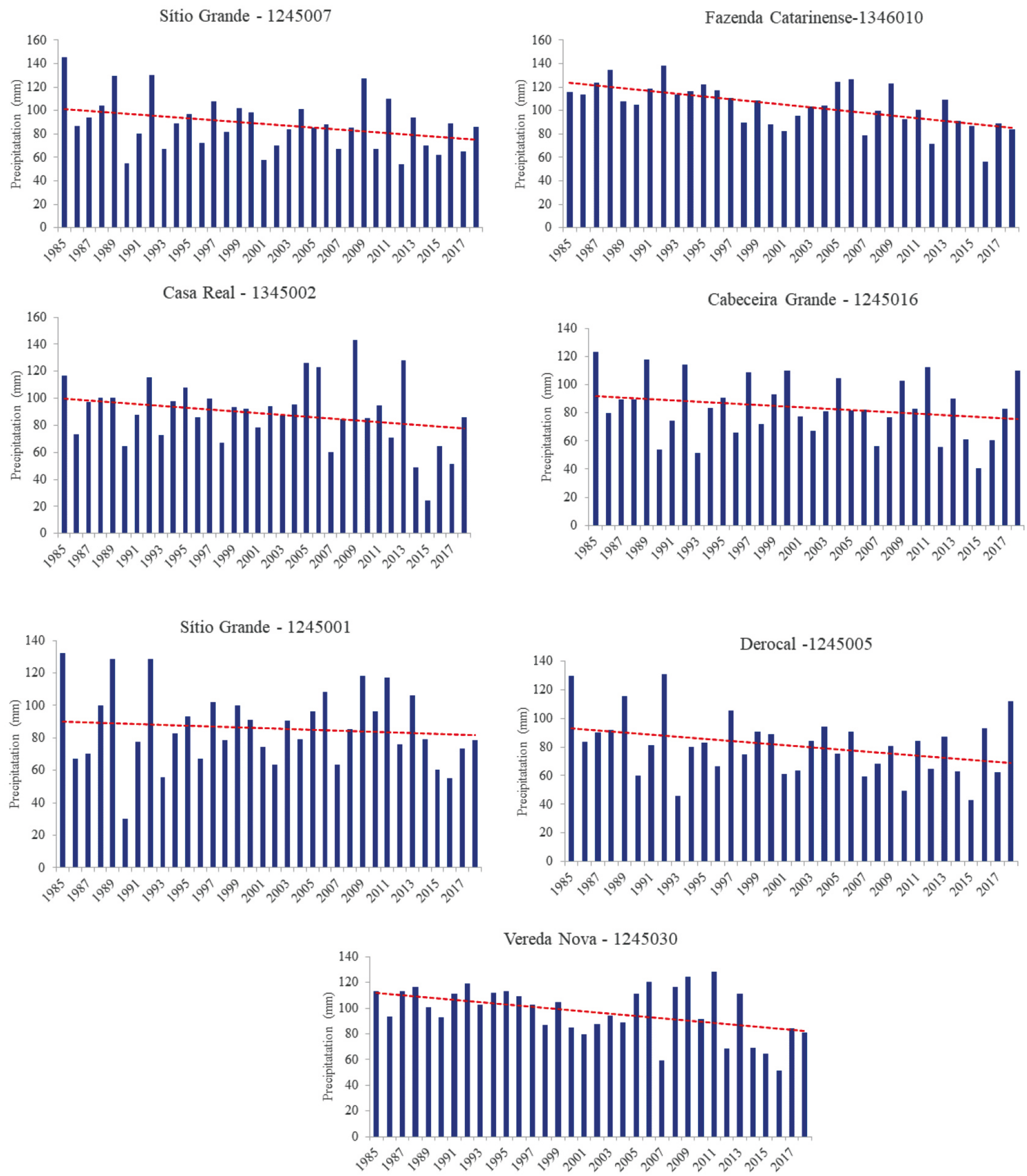

Figure 4 – Average annual precipitation study for each sub-basin in the period of 1985-2018.

Table 3 – Results of Kendall's tau and Sen's slope tests for precipitation.

Station	Z	p-value	Sen's slope
Casa Real	-1.77893	0.0376	-6.42375
Fazenda Catarinense	-3.64681	0.0001	-14.4085
Sítio Grande 5007	-1.74948	0.0401	-6.18794
Vereda Nova	-2.31261	0.0103	-11.8394

Areas known for agriculture increased from 3.95% (62.99 km2) in 1985 to 33.56% (232.24 km2) in 2018 and sum up a change of 750,34% of the total evolution of agricultural areas. The second class of major changes was pasture (from 62.99 km² - 1.23% in 1985, to 232.24 km² - 4.54% in 2018). The smaller magnitude of changes in pasture areas can be justified by the economic change in western Bahia, initially founded in extensive agriculture then gradually changed to mechanized (Santos et al., 2018).

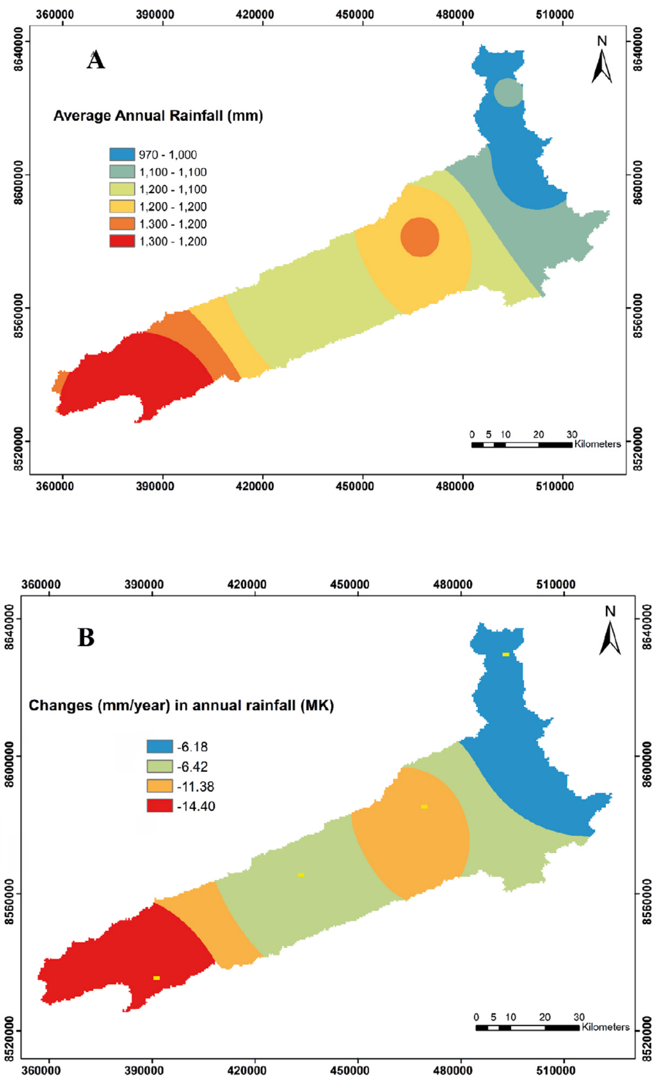

Figure 5 – (A) Spatial distribution of average annual rainfall (mm/year); (B) trends in average annual rainfall (mm/year) for the period of 1985–2018 using MK and Sen'Slope.

Urban areas grew by 0.004%, representing a small evolution and defining the region as strictly agricultural. As for natural areas, all changes signaled a reduction. The rural formations are the class that presents the smallest reduction in area, encompassing three main phytophysiognomy types: Dirty, Clean and Rupestrian Field. These formations do not present a formed canopy and few herbaceous-shrub substrates, facilitating the transformation of these areas into agricultural fields, without any legal restrictions as it is not a dense forest area.

Even so, the areas with denser natural formations such as forests and savanna formations, suffered reductions in smaller magnitudes (-22.29 e 23.17% respectively).

Statistical tests were applied for each class of use and occupation. The reduction in forested areas corroborates with the results of the tests (Table 2). The MK test signals a decreasing and statistically significant trend. The magnitude given by the Sen's slope test indicates deforestation patterns in the forest, field, and savanna series (-1.48, -24.87, -31.52, respectively).

According to Sen Slope, the greatest magnitude of change is statistically proven in agricultural areas (51.69) and the second highest magnitude occurs in the field class with a negative trend (-31.52), mainly proving the replacement of savanna areas for other types of land use classes. The Pettit test indicates that the point of change in the flow coincides with the point of change in urban areas (1999), as well as the turning point for the classes of forest and savanna (2002), agriculture and field (2001), which confirms the magnitude of land use changes, as well as in the flow.

The impacts associated with sudden changes in the landscape are reported by recent studies (Acheampong et al., 2019; Doggart et al., 2020) which highlight that deforestation and the rise of agricultural areas affect the hydrological regime directly, due to the use of groundwater for irrigation. The use of confined water can damage the longevity of rivers in the region. According to Pimentel et al. (2000), the contribution of the Urucuia complex (which supplies the region's hydrogeological refills) is 258.50 mm.year-1 estimated for the period (1984 – 1995), which represents only 20% of the precipitated rainfall volume. Over-exploration of this complex can lead to bankruptcy in the supply of rivers in the region, as is the case with the Rio Grande tributary.

Correlation analysis between the variables flow, land use and rainfall

The results of the Rho Spearman test (Table 5) showed a high correlation between the variables land use and flow: above 73%, except for the precipitation variable, which presented a low correlation (-0.44).

The areas anthropized by agriculture, pasture, and urban infrastructure showed a negative correlation (-0.91, -0.90, -0.88, respectively to Spearman Rho and 0.96, 0.84, 0.82, to MK), representing a high correspondence with the decline in the flow, while the natural areas presented 0.81, 0.78, 0.92 (SR) and 0.76, -0.89, -0.96 (MK) to forest, savanna and fields, respectively. These changes have a high correlation with the flow, indicating that the drop in the flow is related to the drop in the values of these classes.

The low correlation indicated by the Spearman Rho test in the rainfall data corroborates that although there is a negative trend, it does not present a significant magnitude and it cannot be considered as the cause in the decline of the flows to the Rio Grande tributary .

The correspondence between the rise of agricultural areas and the decrease in flow, without detecting changes in behavior in the rainfall regime was also reported by Ferreira et al. (2020), from 1985 to 2014, the variables were independent and point out that precipitation did not impact the flow.

Legendas do eixo X e Y muito pequenas. Solicitamos nova figura aos autores

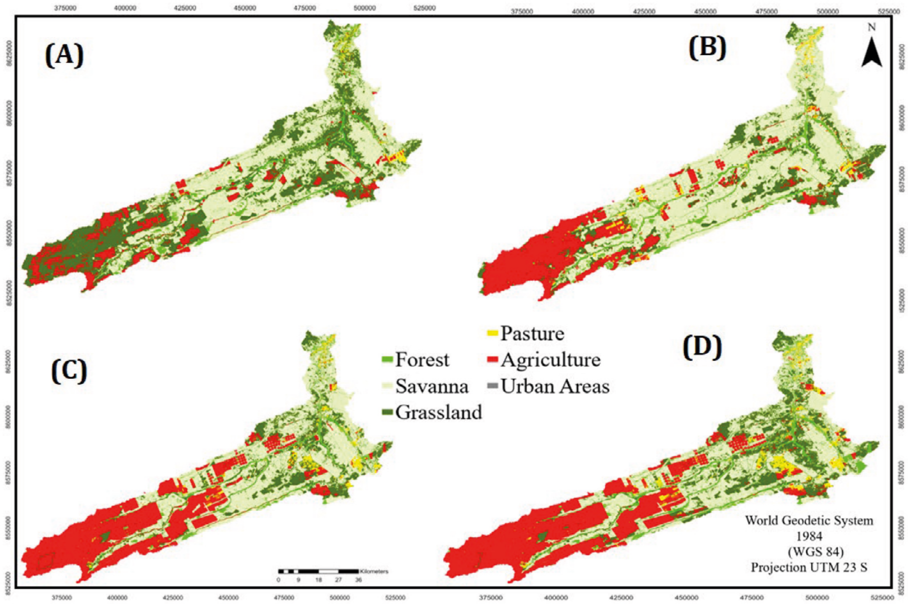

Figure 6 – Map of temporal evolution of land use and occupation in Rio das Fêmeas. (A) Period of 1990; (B) Period of 2000; (C) Period of 2015; (D) period of 2018.

Table 4 – Area of each class of land use (km²) and percentage of the total area of the basin.

Year	Forest	Savanna	Grassland	Pasture	Agriculture	Urban areas
			Km²			
1985	205.298	3,314.85	1,328.98	62.9913	201.84	0
1990	218.14	3,212.3	1,097.19	87.809	538.78	0
2000	181.239	3,127.9	931.976	129.996	742.829	0.01
2015	157.688	2,623.89	478.144	193.304	1,660.84	0.09
2018	159.53	2,546.88	458.75	232.24	1,716.32	0.22
			Percentage of areas (%)			
1985	4.01	64.82	25.99	1.23	3.95	0.000
1990	4.27	62.81	21.45	1.72	10.54	0.000
2000	3.54	61.16	18.22	2.54	14.53	0.000
2015	3.08	51.31	9.35	3.78	32.48	0.002
2018	3.12	49.80	8.97	4.54	33.56	0.004
Changes	-22.29	-23.17	-65.48	268.69	750.34	0.004

Table 5 – Spearman's rho tests results for streamflow, precipitation and land use classes (annual).

Parameter	Spearman test	
	rho	*p*
Streamflow	1	1
Precipitation	-0.28	-0.44
Agriculture	-0.80	-0.91
Past	-0.82	-0.90
Urban areas	-0.83	-0.88
Forest	0.83	0.81
Savanna	0.82	0.78
Grassland	0.82	0.92

The impact of these changes in the water regime is also reported by Silva (2019), who pointed out the replacement of forested areas by pastures and agricultural areas change the physical-chemical composition of the soils, making it more compact, indicating that water tends to travel with more difficulty and consequently the water table is lowered. This fact significantly reduces the recharge of rivers by lateral flow and base runoff, mainly threatening the minimum flows in dry periods. Thus, the reduction in flow is related to the increase in the catchment for irrigated agriculture, which had a great development in the region over the period considered in this study.

Conclusion

Statistical tests pointed out that the average annual flow of the Sítio Grande fluviometric station located in the Rio Grande tributary is not stationary, since a decreasing trend was detected over the 34 years analyzed, with an abrupt changing point in 1999 which is also the breaking point for urban areas.

In the rainfall series, declining trends were detected. Only four rainfall stations presented a drop and they are located along the basin. However, these changes do not reach 20 mm/year.

The Rho Spearman test corroborates with the low correlation in changes in the average annual flow with the precipitation data (rho -0.28) and strong correlation with the changes in the landscape (rho -0.80, -0.82, -0.83, 0.83, 0.82, 0.82). Anthropized areas showed greater correspondence with the declining inflow, which allows us to infer that the changes in the flow regime are a consequence of the changes in land use over the 34 years analyzed in the study area. These evidences reinforce that public policies must be implemented so that there is no compromise in the local public supply as well as in agricultural activities, the multiple uses must be reviewed so that no sector is harmed. In addition, water use permits must be revised in light of the current conditions of water bodies in the region, which already point to considerable declines, and at this rate of water retention, they are vulnerable.

In general terms, the provision of historical data on rainfall and fluviometric series is an important subsidy for robust statistical analyses, new studies should apply statistical treatments to new variables in the region to provide a more solid scientific understanding incorporated into monitoring programs for better resource management of rivers in the region.

Contribution of authors:

Silva, L.S: Data acquisition, Writing – Original Draft, Writing – Review and Editing. Ferraz, L.L.: Formal analysis, Writing – Review and Editing. Sousa, L.F.: Methodology, Formal Analysis, Supervision. Santos, C.A.S.: Conceptualization, Formal Analysis, Validation, Writing – Review and Editing. Rocha, F.A: Validation, Formal Analysis, Investigation, Supervision.

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