SPATIAL DISTRIBUTION AND TEMPORAL TRENDS IN RAINFALL IN MATO GROSSO DO SUL, BRAZIL

DISTRIBUIÇÃO ESPACIAL E TENDÊNCIAS TEMPORAIS DE PRECIPITAÇÃO NO MATO GROSSO DO SUL, BRASIL

DISTRIBUCIÓN ESPACIAL Y TENDENCIAS TEMPORALES DE LA PRECIPITACIÓN EN MATO GROSSO DO SUL, BRASIL

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ABSTRACT
Knowing the spatiotemporal patterns of precipitation is essential to quantify water supply, flood control, soil erosion, and the possibility of drought in a particular region. In other words, temporal and spatial analysis of precipitation is very important for water resources management. In addition, rainfall is the most important climatological variable in the tropical region. Although an increase in problems related to extreme rainfall events has occurred over the last several decades in Brazil, few studies have been conducted investigating rainfall trends in this country. Therefore, the objective of this work was to evaluate the spatial and temporal variability of rainfall in Mato Grosso do Sul State (Brazil), during the dry season (May to September) and rainy season (October to April) over four decades. For that, initially, a linear regression analysis was applied to identify the direction of the monotonic tendency of the precipitation. Next, the trends were investigated using the nonparametric Mann-Kendall trend method. The Pettitt test was also employed to identify any changes in the time series of precipitation. For the spatial distribution of rainfall data, the Ordinary Kriging was used. The results demonstrated that the Western region of the State (Pantanal South-Mato-Grossense) showed a significant negative trend of precipitation in the rainy season.

KEYWORDS
Spatiotemporal analysis; precipitation pattern; temporal variability; tropical region; trend analysis.

RESUMO
Conhecer os padrões espaço-temporais de precipitação é essencial para quantificar o abastecimento de água, o controle de enchentes, a erosão do solo e a possibilidade de seca em uma determinada região. Em outras palavras, a análise temporal e espacial da precipitação é muito importante para a gestão dos recursos hídricos. Além disso, a precipitação é a variável climatológica mais importante na região tropical. Embora um aumento nos problemas relacionados a eventos extremos de chuva tenha ocorrido nas últimas décadas no Brasil, poucos estudos foram conduzidos investigando as tendências de chuvas neste país. Portanto, o objetivo deste trabalho foi avaliar a variabilidade espacial e temporal das chuvas no estado de Mato Grosso do Sul (Brasil), durante a estação seca (maio a setembro) e

chuvosa (outubro a abril) ao longo de quatro décadas. Para isso, inicialmente, foi aplicada uma análise de regressão linear para identificar a direção da tendência monotônica da precipitação. Em seguida, as tendências foram investigadas usando o método de tendência não paramétrico de Mann-Kendall. O teste de Pettitt também foi empregado para identificar eventuais mudanças nas séries temporais de precipitação. Para a distribuição espacial dos dados pluviométricos, foi utilizada a Krigagem Ordinária. Os resultados demonstraram que a região oeste do estado (Pantanal sul-mato-grossense) apresentou tendência negativa significativa de precipitação no período chuvoso.

PALAVRAS-CHAVE

Análise espaço-temporal; padrão de precipitação; variabilidade temporal; região tropical; análise de tendências.

RESUMEN

Conocer los patrones espacio-temporales de las precipitaciones es fundamental para cuantificar el suministro de agua, el control de inundaciones, la erosión del suelo y la posibilidad de sequía en una región determinada. En otras palabras, el análisis temporal y espacial de la precipitación es muy importante para la gestión de los recursos hídricos. Además, la precipitación es la variable climatológica más importante en la región tropical. Aunque en las últimas décadas se ha producido un aumento de los problemas relacionados con eventos extremos de lluvia en Brasil, se han realizado pocos estudios que investiguen las tendencias de las precipitaciones en este país. Por lo tanto, el objetivo de este trabajo fue evaluar la variabilidad espacial y temporal de las precipitaciones en el estado de Mato Grosso do Sul (Brasil), durante la estación seca (mayo a septiembre) y la estación lluviosa (octubre a abril) a lo largo de cuatro décadas. Para lograr esto, inicialmente se aplicó un análisis de regresión lineal para identificar la dirección de la tendencia de la precipitación monótona. Luego, las tendencias se investigaron utilizando el método de tendencias no paramétrico de Mann-Kendall. También se utilizó la prueba de Pettitt para identificar posibles cambios en la serie temporal de precipitación. Para la distribución espacial de los datos de lluvia se utilizó el Kriging Ordinario. Los resultados demostraron que la región occidental del estado (Pantanal Sul-Mato Grosso) mostró una tendencia negativa significativa en las precipitaciones durante la temporada de lluvias.

PALABRAS CLAVE

Análisis espacio-temporal; patrón de precipitación; variabilidad temporal; región tropical; análisis de tendência.

http://dx.doi.org/10.29183/2447-3073.MIX2023.v9.n5.171-187
ISSN: 2447-0899 (IMPRESSA) | 2447-3073 (ONLINE)
Mix Sustentável | Florianópolis | v.9 | n.5 | p.171-187 | OUT. | 2023

1. INTRODUCTION

Precipitation is the main input element of the water balance, in addition to being a fundamental factor in the occurrence of hydrological processes in a watershed. Thus, knowing the intensity, distribution, and frequency of precipitation enable quantification of water supply, flood control, soil erosion, and the possibility of drought in a particular region. In addition, this knowledge is essential for the effective engineering of hydraulic works. According to Shi *et al.* (2015), changes in precipitation spatiotemporal patterns have great impacts on drought/flood risk and utilization of water resources. Extreme-rainfall-related problems have become more of a concern over the last few decades because of increases in their intensity and frequency (Yilmaz and Perera 2015). Kyselý (2009) affirmed that these changes can also very likely have serious effects on ecosystems, hydrology, and water resources.

Precipitation distribution during the year characterizes the climatic regime of a region. According to Longobardi *et al.* (2016), an unbalanced precipitation distribution determines the presence of seasons with an excessive precipitation and seasons during which a deficit occurs, with obvious implications for water resources management. According to Smalley and L'Ecuyer (2015), even if the monthly average volume or frequency of precipitation does not change in an area, changes in the spatial and temporal distribution may still be important for agriculture, flooding, and other hydrologic applications. Milly *et al.* (2008) emphasized that practical decision-making for infrastructure and land use under forecasts of increasing or decreasing precipitation volume can only be completed with this localized information.

Many studies have been conducted to investigate the temporal and spatial variability of precipitation around the world. Some examples can be shown from Africa (e.g., Oguntunde *et al.* 2011, Zhang *et al.* 2012, Nyeko-Ogiramoi *et al.* 2013, Sarr *et al.* 2013), America (e.g., Sahoo and Smith 2009, Nalley *et al.* 2012), Asia (e.g., Pal and Al-Tabbaa 2009, Cong *et al.* 2010, Hanif *et al.* 2013, Shi *et al.* 2015, Daneshmand and Mahmoudi 2017), Europe (e.g., Hidalgo-Muñoz *et al.* 2011, Dabanlı *et al.* 2016, Longobardi *et al.* 2016) and Oceania (e.g., Yilmaz and Perera 2015).

Zhang *et al.* (2012) evaluated the temporal and spatial variations of precipitation and examined the relationship of moisture flux and precipitation trends in Sudan during the period 1948–2005. The authors verified that annual and monthly precipitation had greater spatial variability, and that precipitation of the main rainy season and annual total precipitation in the central part of Sudan significantly decreased during the analyzed period. Nalley *et al.* (2012) co-utilized the Discrete Wavelet Transform technique and the Mann–Kendall trend tests to analyze and detect trends in monthly, seasonally based, and annual data from seven meteorological stations in Southern Ontario and Quebec, Canada, during the period 1954–2008. The results showed that in general, intra and inter-annual events (up to 4 years) were more influential in affecting the observed trends.

Shi *et al.* (2015) performed a comparative analysis of spatial-temporal variability in precipitation during the period 1951–2010 in Southwest China and reported a significant seasonality of the rainfall distribution and quite inhomogeneous temporal distribution of the daily rainfall in the studied area. Hidalgo-Muñoz *et al.* (2011) investigated extreme precipitation events on the Southern Iberian Peninsula (Andalusia), Spain, using 86 stations with daily precipitation records for the period 1955–2006. The authors established seasonal and monthly trends for different extreme-precipitation indices. Both the stability and the significance of the trends were examined. The results indicated a significant spatial and seasonal variability. Yilmaz and Perera (2015) investigated the temporal and spatial variability of extreme rainfall in Victoria (Australia). They observed that increasing extreme rainfall trends occurred for short storm durations, whereas decreasing extreme rainfall trends were found for long storm durations.

Rainfall is the most important climatological variable in the tropical region. To understand the rainfall regime, studies are necessary that allow identifying homogeneous regions for the different meteorological elements. Although an increase in problems related to extreme rainfall events has occurred during the last several decades in Brazil, few studies have been conducted investigating rainfall trends in this country. Oliveira *et al.* (2021) analyzed the risks of extreme events occurred in the South region of Mato Grosso do Sul. The same authors affirm that tropical climate regions are characterized for their heavy rainfall events during the summer, and in recent years, as a result of climate change, such events are becoming recurrent. Thus, the objective of this work was to evaluate the spatial and temporal variability in rainfall during the period 1976–2016 in Mato Grosso do Sul State (Brazil) during the dry season (May to September) and rainy season (October to April). Another important point presented in this article is the detailed methodology of statistical analysis of trend of historical data series, as well as the spatial distribution over the decades in dry and rainy periods.

2. METHODOLOGY

2.1. Study area

The study area is in a tropical region of the Brazilian territory, Mato Grosso do Sul State, located in the Brazilian Midwest (Figure 1). The total area of the State is approximately 357.125 km². The elevation of the State ranges from 200 to 600 m above sea level. The State territory is drained by the systems of the rivers Paraná, to the East, and Paraguay to the West. Most of the State is located in the Brazilian Cerrado region. In the Northwest and Western of the State is located 64.64% (89,318 km²) of the area of the largest floodplain on Earth, the Pantanal (Silva and Abdon 1998).

According to the Köppen Climate Classification model (Alvares *et al.* 2013), the Mato Grosso do Sul State includes four different climates: Af, Aw, Am and Cfa. Af is defined as a tropical, hot, without dry season. This climate, as well as Am and Aw, is characterized by temperatures that exceed 18°C during the winter season (June to August). Aw is defined as a tropical, hot, and humid climate. It features well-defined rainy periods (November to April) with a range of precipitation of 750–2.000 mm and pronounced drought from July to September. The annual average rainfall is 1.500 mm. Am is defined as tropical climate, and is characterized by a monsoon pattern with two distinct seasons, an extremely dry winter and a rainy summer. The annual average rainfall for this climate is up to 1.500 mm and the rainfall of the driest month is less than 60 mm. Cfa is a humid subtropical, oceanic climate, without dry season, with hot summer. The temperature of the hottest month is equal to or greater than 22°C. The monthly rainfall of the driest month is higher than 40 mm.

2.2. Rainfall data

Rainfall data were obtained through the Hydrological Information System of the National Water Agency (ANA-HidroWeb 2018). The spatial and temporal pattern of rainfall based on continuous observation of the monthly total records of 149 stations distributed by the State of Mato Grosso do Sul (Table 1), from 1973 to 2016, at regular intervals of 5 years, was analyzed. For the temporal evaluation of the rainfall, the year was divided into a dry season and rainy season and the mean annual precipitation was calculated for each of these two seasons. It should be noted that the periods of record differ among the monitoring stations; the shortest length of record is 20 years (1992–2012), and the longest length of record is 43 years (1973–2016).

2.3. Trend Detection Methods

First, linear regression analysis (Adamowski *et al.* 2010, Zhang *et al.* 2012, Asadieh and Krakauer 2015) was applied in the time series only to identify the direction of the monotonic tendency of the precipitation. This method aimed to find a regression function that decreased the sum of the distances between the adjusted function and the observed data (Naghettini and Pinto 2007). According to Tabari and Talaee (2011), the main statistical parameter drawn from the regression analysis, slope, indicates the mean temporal change in the studied variable. Positive values of slope show increasing trends, while negative values of slope show decreasing trends. The estimated slopes were tested against the hypothesis of a null slope by means of a two-tailed T-test at a 0,05 significance level.

The trends in annual precipitation were investigated during the rainy season (October to April) and the dry season (May to September), using data from 149 stations, applying the nonparametric Mann-Kendall trend method (Mann 1945, Kendall 1975). This method has been widely used (Yue *et al.* 2002, Birsan *et al.* 2005, Shi *et al.* 2015, Yilmaz and Perera 2015, Longobardi *et al.* 2016) to assess the presence of significant trends in meteorological and hydrological time series. The Mann-Kendall test uses the order of all values to evaluate if there are more increasing or decreasing values in the data (Damberg and AghaKouchak 2014). The null hypothesis (H0) of the Mann-Kendall test is "there is no trend". If the calculated z statistic is larger than the critical values (derived from normal distribution tables) at the specified significance levels, then H0 is rejected, and the alternative hypothesis (HA), which is "there is a trend" is accepted (Yilmaz and Perera 2014, 2015). In this study the test was conducted at a 0,05 significance level.

The Pettitt test (Pettitt 1979) was employed to identify any changes in the time series of precipitation. Using the Pettit test, it is possible to identify the point at which a series of data is interrupted, leaving the data series before and after that point significantly different. The null hypothesis (H0) of this non-parametric test is that there is no break point, against the alternative hypothesis (HA) in which there is a change point.

2.4. Spatial distribution of the rainfall data

For the spatial distribution of rainfall data, the Ordinary Kriging was used, who is a common type of Kriging in practice. Ordinary kriging is a geostatistical tool by which the distance between two points is used to predict the semivariance of some dependent variable (Farmer 2016). In this method, the trend is considered as unknown and constant. Ordinary Kriging estimates the unknown precipitation depth at the unsampled location as a linear combination of neighboring observations (Zhang and Srinivasan 2009). Cressie (1993) provide the description of the mathematics of kriging. For analysis of the spatial distribution of precipitation, were considered regular intervals of five years.

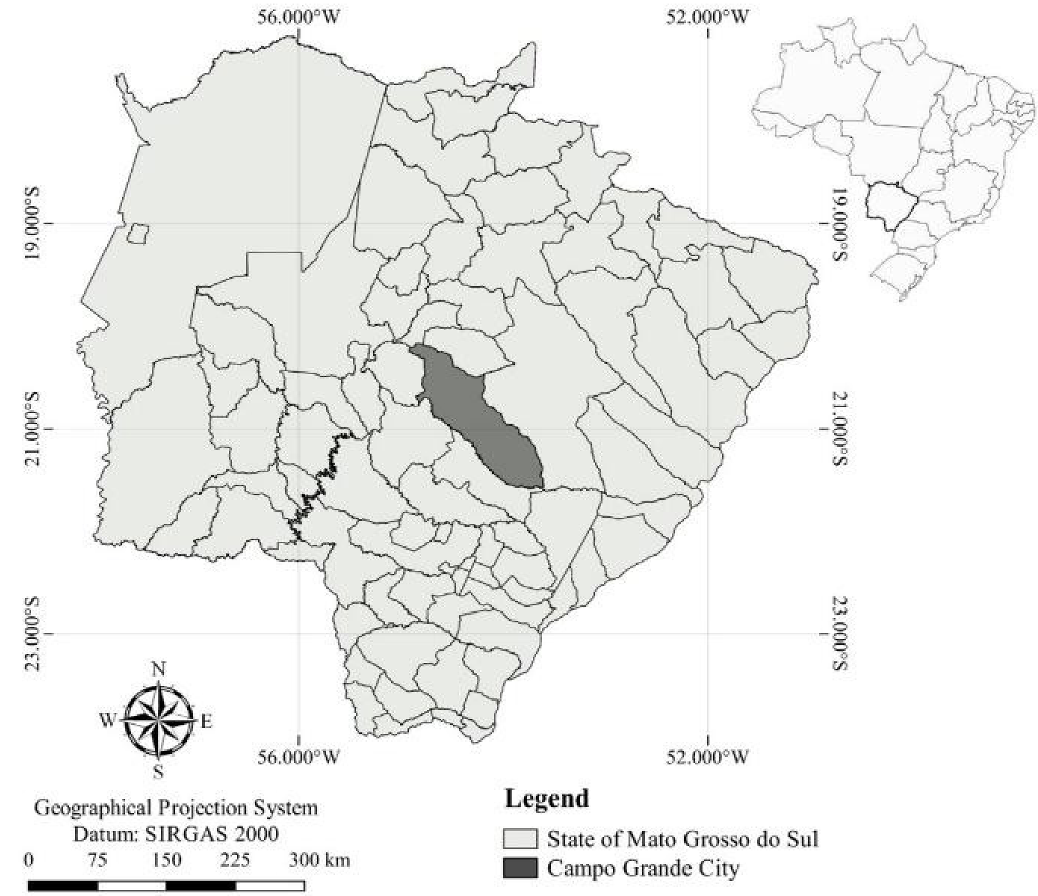


Figure 1: Location of Mato Grosso do Sul State.
Source: Authors.

Code	Station	Latitude	Longitude
1754002	Posto Correntes (MT-163)	17°35'12.84" S	54°45'24.12" W
1754004	Pedro Severo	17°49'50.88" S	54°18'47.16" W
1755001	União	17°47'25.08" S	55°46'24.96" W
1756002	Retiro Seguro	18°01'14.88" S	56°43'54.84" W
1756003	Porto do Alegre	17°37'23.88" S	56°57'54.00" W
1757000	Porto Índio	17°37'00.12" S	57°42'00.00" W
1757003	Bela Vista do Norte	17°38'29.04" S	57°41'26.16" W
1852002	Indáia Grande	18°59'52.08" S	52°35'17.16" W
1852003	Cidade Chapadão Gaucho	18°41'30.12" S	52°35'38.04" W
1853001	Figueirão	18°43'59.88" S	53°40'59.88" W
1853002	Cachoeira Polvora	18°11'26.16" S	54°15'28.08" W
1853004	Costa Rica	18°32'49.92" S	53°08'07.08" W

https://doi.org/10.29183/2447-3073.MIX2023.v9.n5..165-181

Code	Station	Latitude	Longitude
1853005	Colônia Figueirão	18°40’46.92” S	53°38’16.08” W
1854000	Coxim	18°30’15.12” S	54°44’04.92” W
1854001	Pedro Gomes	18°05’54.96” S	54°32’49.92” W
1854002	Rio Verde de Mato Grosso	18°54’36.00” S	54°49’55.92” W
1854003	Jauru	18°38’57.12” S	54°21’25.92” W
1854004	Coxim	18°30’15.12” S	54°45’20.16” W
1854006	Confluência do Rio Jauru	18°43’49.08” S	54°34’42.96” W
1855000	Fazenda São Gonçalo (Partic.)	18°21’00.00” S	55°51’00.00” W
1857001	Amolar	18°02’25.08” S	57°29’26.88” W
1857002	São José do Mato Grande	18°14’11.04” S	56°58’23.16” W
1857003	São Francisco	18°23’38.04” S	57°23’27.96” W
1951002	Paranaíba	19°39’48.96” S	51°11’26.88” W
1951003	Fazenda Pindorama	19°23’26.88” S	51°36’32.04” W
1951004	Arvore Grande	19°13’45.12” S	51°52’30.00” W
1951005	Inocência	19°44’11.04” S	51°56’00.96” W
1952000	Alto Sucuriu	19°26’39.12” S	52°33’29.88” W
1952001	Pontal	19°40’41.16” S	52°53’47.04” W
1952002	Morangas	19°33’12.96” S	52°09’59.04” W
1952003	São José do Sucuriu	19°57’47.88” S	52°13’33.96” W
1953000	Alto Rio Verde	19°22’36.84” S	53°34’10.92” W
1953001	Vista Alegre	19°47’04.92” S	53°57’50.04” W
1953003	Furlaneto	19°16’18.84” S	53°29’26.88” W
1953004	Porto de Pedras	19°03’18.00” S	53°00’54.00” W
1954002	Rochedo	19°57’11.88” S	54°52’42.96” W
1954003	Rio Negro	19°26’22.92” S	54°58’59.88” W
1954004	Camapuã	19°29’48.12” S	53°59’48.12” W
1954005	Bandeirantes	19°55’04.08” S	54°21’30.96” W
1954006	Fazenda Caranda	19°19’19.92” S	54°09’39.96” W
1955000	Iguaçu	19°56’40.92” S	55°47’39.84” W
1956001	Paraíso	19°10’23.88” S	56°42’43.92” W
1956002	Rio Negro (Fazenda)	19°34’00.12” S	56°12’00.00” W
1956003	Entre Rios	19°41’48.12” S	56°16’58.08” W
1956004	Campo Alto	19°00’11.88” S	56°05’20.04” W
1956005	Bodoquena	19°52’14.88” S	56°59’00.96” W
1956006	Porto Carreiro (Particular)	19°57’00.00” S	56°52’59.88” W
1956008	São Sebastião	19°21’33.12” S	56°24’33.12” W
1957000	Corumbá	19°00’00.00” S	57°38’60.00” W
1957002	Corumbá (ETA)	19°00’20.88” S	57°36’06.84” W
1957003	Porto da Manga	19°15’29.88” S	57°14’07.08” W
1957004	Forte Coimbra	19°55’06.96” S	57°47’21.84” W
1957005	Piraputanga	19°18’19.08” S	57°35’35.88” W
1957006	Porto Esperança	19°36’02.88” S	57°26’17.16” W
2051000	Três Lagoas	20°47’40.92” S	51°42’46.08” W
2051037	Jupiá	20°48’00.00” S	51°37’59.88” W
2051045	Selvíria	20°21’48.96” S	51°25’26.04” W
2051046	Aparecida do Taboado	20°04’05.88” S	51°06’12.96” W
2052002	Água Clara	20°26’43.08” S	52°54’06.84” W

https://doi.org/10.29183/2447-3073.MIX2023.v9.n5..165-181

Code	Station	Latitude	Longitude
2052003	Fazenda Rio Verde	20°06'06.84" S	52°55'32.88" W
2052004	Garcias	20°36'10.08" S	52°13'05.88" W
2052006	Porto Galeano	20°05'38.04" S	52°09'37.08" W
2053000	Ribas do Rio Pardo	20°26'40.92" S	53°45'29.16" W
2053001	Usina Mimoso	20°40'36.84" S	53°34'17.04" W
2053004	Campos Elisios	20°57'39.96" S	53°17'17.16" W
2054000	Campo Grande	20°26'39.12" S	54°43'21.00" W
2054001	Campo Grande (SBCG)	20°28'00.12" S	54°40'00.12" W
2054002	Sidrolândia	20°55'59.88" S	54°58'00.12" W
2054003	Jaraguari	20°08'60.00" S	54°23'60.00" W
2054005	Jaraguá	20°29'35.16" S	54°48'41.04" W
2054009	Santa Elisa	20°29'26.16" S	54°52'00.84" W
2054010	Caixa d'água	20°27'00.00" S	54°37'59.88" W
2054011	Lageado - Tomada d'água - SAEE	20°27'00.00" S	54°37'59.88" W
2054012	Usina e Tratamento - SAEE	20°27'00.00" S	54°37'59.88" W
2054013	Conjunto Ferroviários - SAEE	20°27'00.00" S	54°37'59.88" W
2054014	DNOS - 8.DRS	20°27'06.12" S	54°37'39.00" W
2054015	Rua São Paulo 565 - SAEE	20°27'00.00" S	54°37'59.88" W
2054016	Rua Própria 44	20°27'00.00" S	54°37'59.88" W
2054017	Rua Bahia 400 - SAEE	20°27'00.00" S	54°37'59.88" W
2054018	Rua das Paineiras - SAEE	20°27'00.00" S	54°37'59.88" W
2054019	Jaraguari	20°06'07.92" S	54°26'04.92" W
2054020	Alegre	20°28'14.88" S	54°05'48.12" W
2054021	Sidrolândia	20°57'05.04" S	54°58'18.12" W
2055000	Aquidauana	20°27'24.12" S	55°40'17.04" W
2055001	Cipolândia	20°07'40.08" S	55°23'35.88" W
2055002	Palmeiras	20°26'56.04" S	55°25'50.88" W
2055003	Fazenda Lajeado	20°17'31.92" S	55°26'43.08" W
2055004	Taboco	20°04'13.08" S	55°38'43.08" W
2056001	Miranda	20°14'26.88" S	56°23'44.88" W
2056003	Estrada MT-738	20°45'51.84" S	56°05'35.16" W
2056005	Guaicurus	20°06'06.84" S	56°47'43.08" W
2056006	Miranda	20°13'59.88" S	56°22'59.88" W
2056007	Santa Rosa	21°01'54.84" S	56°59'17.16" W
2057000	Tarumã	20°17'26.88" S	57°38'52.08" W
2057001	São Simão	20°02'58.92" S	57°19'17.04" W
2152000	Porto Velho	20°48'02.16" S	52°23'17.88" W
2152001	Porto Uerê	21°43'32.88" S	52°20'03.12" W
2152005	Xavantina do Sul	21°17'43.08" S	52°48'38.16" W
2152014	Fazenda Boa Esperança	21°14'57.84" S	52°17'17.16" W
2152016	Fazenda Mimosinho	21°04'10.92" S	52°59'36.96" W
2153000	Porto Pindaíba	21°36'55.08" S	53°03'07.92" W
2153002	Passagem Ribeirão Lontra	21°24'33.84" S	53°36'47.88" W
2153003	Xavante	21°58'55.92" S	53°26'20.04" W
2153005	Fazenda Divisa	21°12'41.04" S	53°57'24.84" W
2153004	Lanceiro	21°01'22.08" S	53°32'12.84" W
2154000	Aroeira	21°38'49.92" S	54°25'31.08" W

Code	Station	Latitude	Longitude
2154001	Porto Rio Brilhante	21°48'21.96" S	54°36'11.16" W
2154002	Vau do Balsamo	20°59'38.04" S	54°30'29.16" W
2154005	Fazenda São Francisco	21°00'00.00" S	54°00'00.00" W
2154006	Retiro Guarujá	21°52'18.12" S	54°04'50.88" W
2154007	Capão Bonito	21°10'58.08" S	54°44'45.96" W
2154008	Fazenda Ponte	21°18'06.84" S	54°11'57.84" W
2155000	Maracaju	21°37'06.96" S	55°08'12.84" W
2155001	Nioaque	21°08'57.12" S	55°49'30.00" W
2156000	Bonito	21°07'05.88" S	56°28'48.00" W
2156001	Jardim	21°26'26.16" S	56°05'26.88" W
2156002	Figueira (Fazenda)	21°30'42.84" S	56°42'06.12" W
2157003	Santa Otília	21°11'30.84" S	57°02'21.12" W
2157004	Porto Murtinho	21°42'05.04" S	57°53'30.12" W
2157005	Marabá	21°41'20.04" S	57°21'34.92" W
2157006	Barranco Branco	21°05'56.04" S	57°50'40.92" W
2252000	Anaurilândia	22°11'11.04" S	52°42'47.88" W
2253000	Uhe Itaipu Ivinhema	22°22'58.08" S	53°31'55.92" W
2253004	Ivinhema	22°18'18.00" S	53°49'51.96" W
2253014	Bataipora	22°17'54.96" S	53°16'49.08" W
2253015	Fazenda Jangada	22°32'42.00" S	54°01'40.08" W
2254000	Caarapó	22°37'27.84" S	54°49'28.92" W
2254001	Dourados	22°23'53.16" S	54°47'30.12" W
2254002	Dourados	22°23'53.16" S	54°47'31.92" W
2254003	Glória de Dourados	22°24'20.88" S	54°14'07.08" W
2254004	Porto Wilma	22°04'31.08" S	54°11'21.12" W
2254005	Itaporã	22°04'28.92" S	54°47'02.04" W
2255000	Ponta Porã	22°31'59.88" S	55°43'00.12" W
2255001	Ponta Porã	22°31'59.88" S	55°42'00.00" W
2255002	Antônio João	22°11'17.16" S	55°56'36.96" W
2255003	Bocaja	22°43'54.84" S	55°14'31.92" W
2255004	Itaum	22°05'09.96" S	55°21'11.16" W
2256001	Bela Vista	22°06'36.00" S	56°31'39.00" W
2257000	Caracol	22°00'51.12" S	57°01'55.92" W
2257001	São Carlos	22°13'22.08" S	57°18'16.92" W
2353048	Fazenda Vaca Branca	23°04'22.08" S	53°49'14.16" W
2354000	Naviraí	23°03'28.08" S	54°11'38.04" W
2354001	Iguatemi	23°40'54.84" S	54°33'42.12" W
2354002	Florida	22°58'13.08" S	54°33'47.88" W
2354004	Colônia Bom Jesus	23°26'58.92" S	54°23'36.96" W
2355000	Amambaí	23°05'52.08" S	55°14'36.96" W
2355001	Coronel Sapucaia	23°15'57.96" S	55°31'27.84" W
2355002	Porto São Domingos	23°39'01.08" S	55°23'30.84" W
2355003	Tacuru	23°38'25.08" S	55°01'09.12" W

Table 1: Rainfall monitoring stations
Source: Authors.

3. RESULTS AND DISCUSSIONS

Precipitation is the main input element of the water balance, in addition to being a fundamental factor in the occurrence of hydrological processes in a watershed. Thus, knowing the intensity, distribution, and frequency of precipitation enable quantification of water supply, flood control, soil erosion, and the possibility of drought in a particular region. In addition, this knowledge is essential for the effective engineering of hydraulic works.

According to Shi *et al.* (2015), changes in precipitation spatiotemporal patterns have great impacts on drought/flood risk and utilization of water resources. Extreme-rainfall-related problems have become more of a concern over the last few decades because of increases in their intensity and frequency (Yilmaz and Perera 2015). Kyselý (2009) affirmed that these changes can also very likely have serious effects on ecosystems, hydrology, and water resources.

3.1. Rainfall temporal analysis

According to the linear regression analysis, it was observed that, during the dry season, 55,68% of the analyzed stations presented a positive trend (increasing pattern) and 44,32% presented a negative trend (decreasing pattern). However, during the rainy season, 41,76% of the stations presented a positive trend (increasing pattern) and 58,24% presented a negative trend (decreasing pattern). The slope of the regression analysis in the dry season varied from -0,0044 to 0,0045, in the rainy season its presented a larger range, the slope varied from -0,0117 to 0,0052.

The Mann-Kendall test showed different rainfall trends pattern in the study area. The Aw climate domain had thirty one monitoring stations analyzed for rainfall trend, and it comprises four regions of the State: East, North, Northwest and Central. The Aw climate domain presented the slope of the regression analysis varied from -0,0037 to 0,0030 in the dry season and from -0,0117 to 0,004 in the rainy season. The Northern region showed a decreasing tendency in the rainy season for the Porto do Alegre station, with significant trend in the Mann-Kendall test, p value of 0,0128 and τ = -0,134 (Figure 2.a). The Northwestern region also presented a decreasing tendency of precipitated monthly totals in the rainy season. Two stations presented a significant negative trend in the Mann-Kendall test, the São Francisco station with 0,001 p value and τ = -0,208 (Figure 2.b) and the Forte Coimbra station with 0,00005 p value and τ = -0,217 (Figure 2.c). However, the Eastern region presented a significant growing tendency in the rainy season. Two stations presented a significant positive trend in the Mann-Kendall test, the Porto Uerê station with 0,022 p value and τ = 0,0936 (Figure 2.f), and the Fazenda Jangada station with 0,027 p value and τ = 0,109 (Figure 2.g).

The Southwest region of the State, whose domain is the Af climate, had nine monitoring stations analyzed for rainfall trend. In the rainy season, 77,78% of the stations showed a negative trend. The slope of the regression analysis varied from -0,00096 to 0,0045 in the dry season and from -0,0041 to 0,0023 in the rainy season. None station located in the Af climate domain presented a significant trend in the Mann-Kendall test.

In the climate-dominated region Cfa, Southern region of the State, thirteen stations were analyzed. In the rainy season, there was a predominance of a positive tendency. In the dry season there was also an increase in rainfall trend, with nine stations showing an increasing tendency. The slope of the regression analysis varied from -0,0044 to 0,00204 in the dry season and from -0,0033 to 0,0049 in the rainy season. Two stations presented a significant positive trend in the Mann-Kendall test, the Antonio João station with 0,0126 p value and τ = 0,119 (Figure 2.h) and the Amambai station with 0,0267 p value and τ = 0,0937 (Figure 2.i). Amambai was one of the studied cities by Oliveira *et al.* (2021) that were affected by heavy rainfall in November 2015 and experienced a disaster that lasted for a period of 180 days, so the results of the increase tendency of rainfall in the region confirm the results presented.

The Am climate occupies a region that runs from the Northeast to the West of the State. Ten stations were analyzed in the Northeast region. In the rainy season four stations showed an increasing pattern and six showed a decreasing pattern. In the dry season eight stations showed a negative trend. In the Western region there was an increasing tendency of precipitation in the dry season and decreasing in the rainy season. The slope of the regression analysis varied from -0,0039 to 0,0041 in the dry season and from -0,0069 to 0,0052 in the rainy season. The Campos Elísios station presented a significant positive trend in the Mann-Kendall test in both seasons analyzed. For the rainy season it presented a τ = 0,131 with 0,0107 p value (Figure 2.d) and for the dry season a τ = 0,133 with 0,0362 p value (Figure 2.e).

At the Central region is located Campo Grande city, the capital of the Mato Grosso do Sul State. The Mann-Kendall test results showed a significant increasing trend at three rainfall monitoring stations near Campo Grande city (Ribeirão Lontra, Porto Vilma, and Cipolândia) during the rainy season and at two rainfall monitoring stations (Ribeirão Lontra and Palmeiras) during the dry season. A significant upward trend both during the dry season and rainy season was verified at one rainfall monitoring station (Ribeirão Lontra).

Of the rainfall monitoring stations in which significant trends were detected during the dry period of the year, one (Ribeirão Lontra) has an Am climate and the other (Palmeiras) has an Aw climate. However, among the three rainfall stations in which a significant trend was detected during the rainy season, only one (Ribeirão Lontra) had an Am climate, while the other two (Porto Vilma and Cipolândia) had an Aw climate (Figure 3).

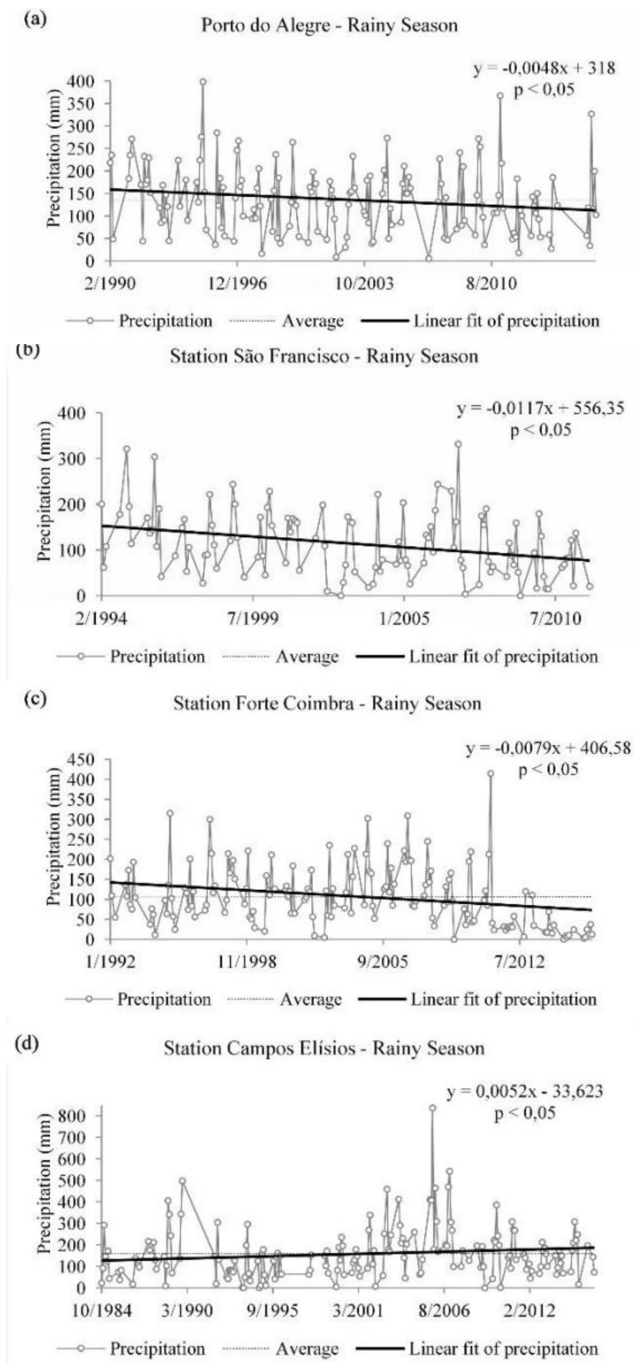
At the Ribeirão Lontra rainfall station, the maximum total rainfall during the dry season did not exceed 200 mm. The Pettitt test showed an abrupt change in the pattern of rainfall in August 1996. During 1997 and 2000, the total rainfall of the period increased to 500 mm and during 2009 reached 619,5 mm. During the rainy season, which also showed a significant trend, an abrupt change was detected during April 1995. At this station, a great variability was observed in the total rainfall for the period, during each year, such that, between 2009 and 2014, total annual rainfall exceeded 1.000 mm, reaching 1.218,6 mm during 2013.

At the rainfall station Porto Vilma, decreases in the total rainfall during some alternate years was apparent, but overall there was an increasing trend considering the total series analyzed. The Pettit test showed a change in the rainfall pattern at the station during April 1994. The upward trend is evidenced by the change in the total rainfall from 807,5 mm during the rainy season of 1986 to 1.422,7 mm during the rainy season of 1997. The Cipolândia station showed a change in the rainfall pattern during the 2000s, more specifically during April 2005. A total rainfall of more than 1.800 mm was observed during the rainy season of 2011.

The data series of the rainfall station Palmeiras presented an abrupt change identified by the Pettitt method during July of 2000. At this station an increasing trend was detected in the total monthly rainfall for the dry period of each year. During 1989, 120 mm was recorded in during June. During 1994 the maximum monthly rainfall was 145 mm, during 1998 it was 160,7 mm, during 2008 it was 171,4, during 2012 it was 203,9 mm, and, in 2016, the maximum recorded rainfall of 226,1 mm during the dry season, was recorded.

Da Silva (2004), conducted a study in Northeastern Brazil and concluded that the relative humidity and rainfall presented a decreasing behavior in that region. The results also suggest that the historical trends may be related to climatic variability in the region, which affects both the semi-arid and coastal parts of the region. Marengo (2004) identified negative rainfall trends for the entire Amazon basin, while at the regional level there was a negative trend in Northern Amazonia and a positive trend in Southern Amazonia. The author observed that the Southern part of the Amazon Basin seems to show similarities to the changes in precipitation in Southern Brazil and Northern Argentina.

Moraes *et al.* (1998), statistically analyzing the Piracicaba river basin in the Southeastern region of Brazil, observed that precipitation and evapotranspiration data showed significant increasing trends. However, the flow data showed a significant decreasing trend. Therefore, the most probable cause of this decreasing behavior is the exportation of water from the basin to the metropolitan region of São Paulo, indicating anthropogenic intervention in the behavior of the hydrological cycle.



https://doi.org/10.29183/2447-3073.MIX2023.v9.n5..165-181

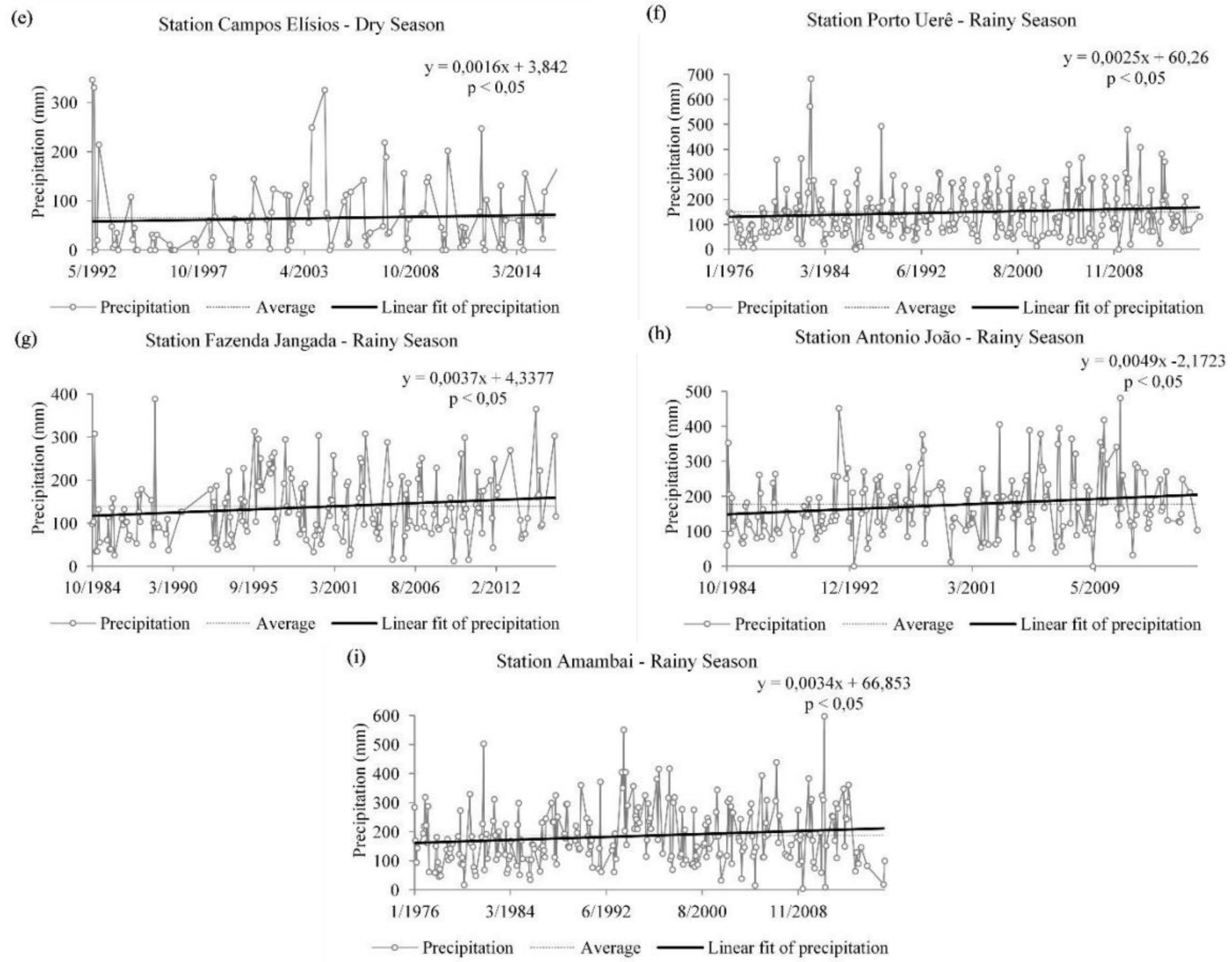


Figure 2: Rainfall monitoring stations of different regions of Mato Grosso do Sul State.
Source: Authors.

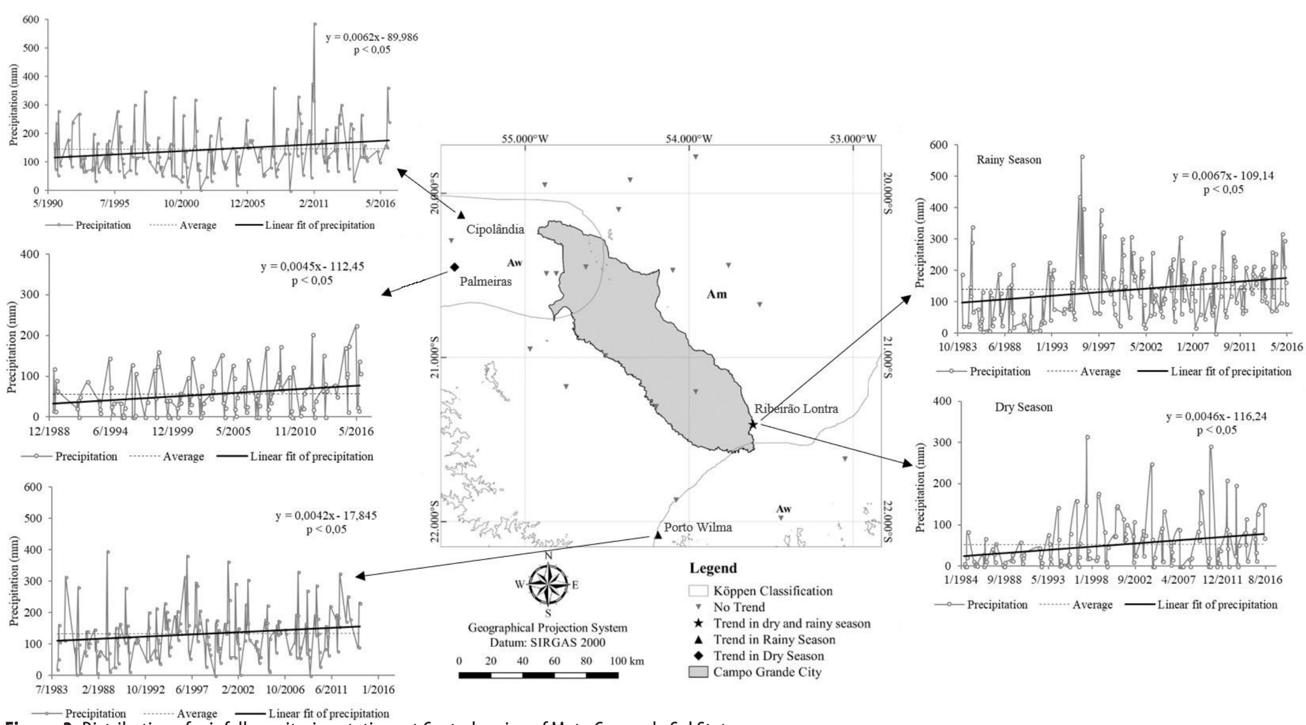


Figure 3: Distribution of rainfall monitoring stations at Central region of Mato Grosso do Sul State.
Source: Authors.

All the significant trends detected in the Central region were ascending. According to Lima *et al.* (2021) the city of Campo Grande presents a monthly rainfall average of approximately 150 mm in the rainy season, and approximately 55 mm in the dry season, however 0 mm and 460 mm have been registered for some months in the dry and rainy seasons, respectively, with extreme events recurrently registered in the rainy season. Through a Disaster Information Form (FIDE) of the Brazilian Ministry of National Integration, regulated by Normative Instruction No. 2, dated 12/20/2016 (Brazil 2016), the Emergency Municipality (SE) was recognized by the municipality of Campo Grande during 2006, 2010, 2011, 2014, and 2016 because of floods, landslides, local storms, and linear erosion. All these hydrometeorological disasters occur more frequently and severely if the temporal trend of rainfall in the region is increasing. Thus, the results obtained serve as an alert, because all rainfall stations in which a significant trend was detected have an increasing pattern of precipitation.

3.2. Spatial analysis of rainfall

Considering the rainy season, during all the time intervals, the highest rainfall occurred in the Northeast region of the State (Figure 4). While the lowest rainfall occurred during the interval 1976 to 1980 was concentrated in the South region, that is, precipitation decreased from North to South of the State. In the intervals 1981 to 1985, 1986 to 1990 and 1991 to 1995, the lowest rainfall occurred concomitantly in the East and West, with medium precipitation in the Central area of the State. Already, from 1996 to 2000 and 2001 to 2005 the lowest rainfall (130 to 140 mm) was concentrated in the West region. The intervals 2006 to 2010 and 2011 to 2015, the area that concentrated the lowest rainfall was also the Western region, however the minimum rainfall heights reached 110 mm. Thus, the highest rainfall tends to be concentrated in the Northeastern part of the State, with little change in that. However, the Western region of the State, where the Pantanal South-Mato-Grossense is located, has undergone a gradual decrease of rainfall, and in almost all periods was the place that presented the lowest rainfall.

Considering the rainy season, in all the analyzed periods, the highest rainfall heights are concentrated in the Northeastern region of Mato Grosso do Sul. The monthly total precipitated in the months of the rainy season showed a decrease in the region of the Pantanal South-Mato-Grossense (Western region of the State). According to Bergier *et al.* (2018), in general the decadal trend of seasonal precipitation was not statistically significant for all seasons analyzed in their study, which means that despite the interannual variability, the average amount of rainfall on the Brazilian Pantanal did not change significantly over the seasons at the last nine decades. The results obtained by Bergier *et al.* (2018) are according to Boers *et al.* (2017) and reinforce the importance of the Amazon rainforest in the redistribution of precipitable water in South America. According to Nobre (2014), along the Amazon deforestation arc, precipitation decreased due to the reduction of surface moisture fluxes.

By analyzing the dry season over time, it was verified that the highest rainfall levels were concentrated mainly in the Southern region of the State (Figure 5), which borders Paraguay and Paraná State (Brazil). The lowest rainfall amounts were concentrated in the North region of Mato Grosso do Sul State. It was only in the period 1981 to 1985 that the highest rainfall intensity was concentrated more Southwest the State. Considering the dry season, during the intervals from 2001 to 2005, 2006 to 2010 and 2011 to 2015 it is noticeable that the highest rainfall heights are smaller in these periods of time than others, a situation similar to that happened in 1981 to 1985. It is noted that the highest rainfall heights in the dry season of the year tend to be concentrated in the Southern region of the State. However, the highest rainfall in this region has been decreasing with time. This can be observed comparing the periods 2006 to 2010 and 2011 to 2015, where the monthly precipitation average reached 80 mm, with the previous periods where the average monthly precipitation for the dry period exceeded 100 mm. This behavior of rainfall reduction can also be noticed in the lowest rainfall concentrated in the Northern region of the State, comparing the period from 1976 to 1980 with 2011 to 2015.

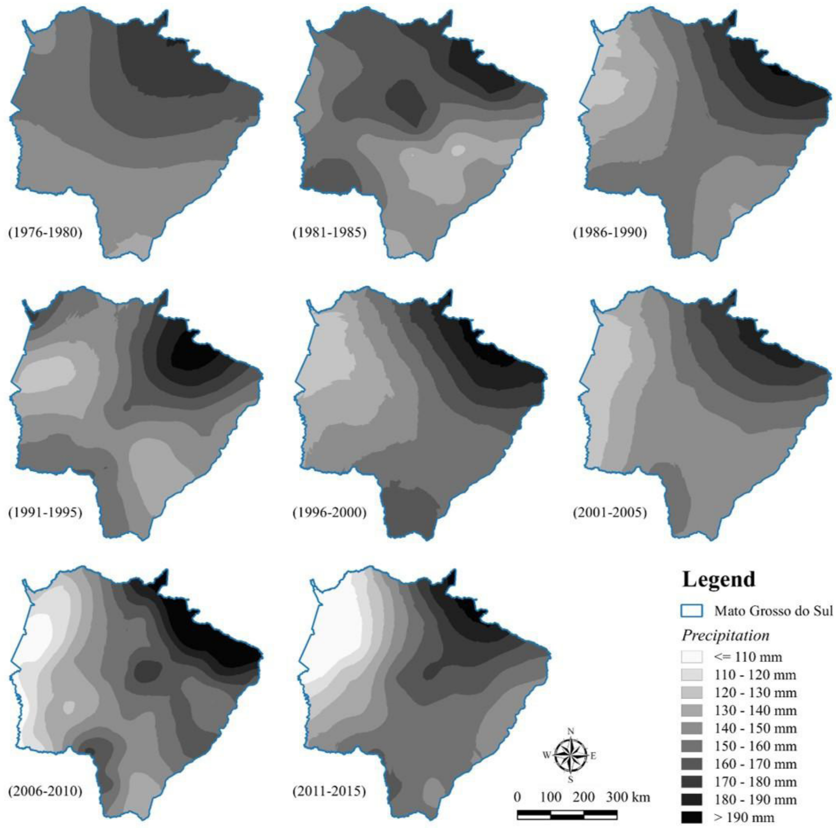


Figure 4: Spatial distribution of rainfall during the rainy season for 5-year intervals.
Source: Authors.

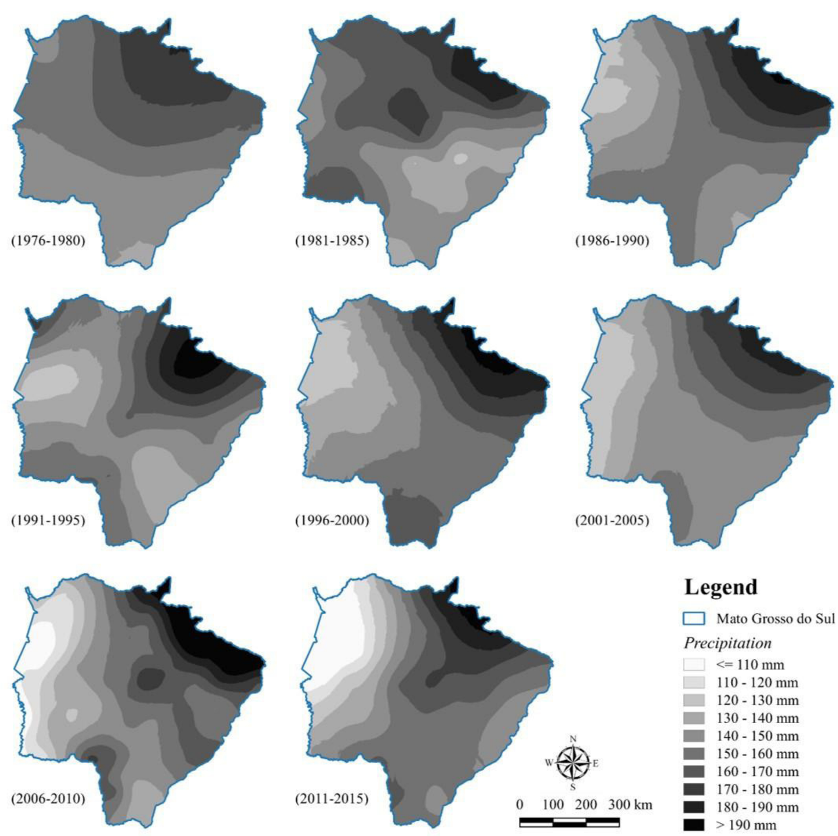


Figure 5: Spatial distribution of precipitation during the dry season for 5-year intervals.
Source: Authors.

4. CONCLUSION

In Mato Grosso do Sul State, the most significant change in the rainfall trend pattern occurs at the rainy season.

The monthly total precipitated in the rainy and in the dry season showed a decrease pattern in the region of the Pantanal South-Mato-Grossense (Western region of the State). In the region was also detected a significant negative trend of precipitation in the rainy season.

There is a growing trend in rainfall amount in the municipal area of Campo Grande, which has become more pronounced during recent years. This trend is higher during the rainy season, but it is also evident during the dry season. The observation of a significant tendency of an in increase in the mean height of rainfall over the years justifies the reduction in the time intervals between hydrometeorological disasters recorded by official means, mainly in the urbanized area of the Municipality of Campo Grande.

The analyses have implications for future scenarios during the rainy season, once the trend become more intense and recurrent.

Hydrometeorological disasters more frequently and severely occur if the temporal tendency of the precipitation in the region is ascending.

The study of the precipitation characteristics in this region can assist public administration in decision making regarding water resources management.

ACKNOWLEDGMENTS

This study was partially financed by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001. The authors are grateful to the Programa de Apoio à Pós-graduação – PROAP, to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), to the Fundação de Apoio ao Desenvolvimento do Ensino, Ciência e Tecnologia do Estado de Mato Grosso do Sul, and to the Federal University of Mato Grosso do Sul - UFMS for their support in the development of this work.

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HOW TO CITE THIS ARTICLE

LEITE, Izabel Rodrigues; FINCK, Luiz Felipe; ALMEIDA, Aleska Kaufmann; CORREA, Jovane Martins; COSTA, Cássia Monteiro da Silva Burigato; ALMEIDA, Isabel Kaufmann de. Spatial distribution and temporal trends in Rainfall in Mato Grosso do Sul, Brazil. **MIX Sustentável**, v. 9, n. 5, p. 165-181 2023. ISSN 244-73073. Available in: <http://www.nexos.ufsc.br/index.php/mixsustentavel>. Access in: DD/MM/YYYY doi: <https://doi.org/10.29183/2447-3073.MIX2023.v9.n5.165-181>.

SUBJECTED IN: 22/04/2023
ACCEPTED IN: 21/09/2023
PUBLISHED IN: 30/10/2023
RESPONSIBLE EDITOR: Lisiane Ilha Librelotto e Paulo Cesar Machado Ferroli

Record of authorship contribution:
CRediT Taxonomy (http://credit.niso.org/)

IRL: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing the Original Draft and Review and Editing, Visualization.

LFF: Conceptualization, Methodology, Software, Writing the original Draft, Review and Editing; Visualization.

AKA: Conceptualization, Methodology, Software, Writing the Original Draft and Review and Editing, Visualization.

JMC: Investigation, Software, Writing the Original Draft.

CMSBC: Investigation, Writing the Original Draft.

IKA: Conceptualization, Methodology, Validation, Formal analysis, Writing the Original Draft and Review and Editing, Visualization, Supervision, Funding acquisition.

Conflict declaration: nothing has been declared.