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Variability, trends and extreme precipitation events in Goiânia - GO

Variabilidade, tendências e eventos extremos de precipitação em Goiânia - GO

Variabilidad, tendencias y eventos extremos de precipitación en Goiânia – GO

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Abstract: Although Goiânia is a relatively young and medium-sized city, it has faced recurring problems caused by both excess and scarcity of rainfall. Considering the widespread, accelerated, and historically unprecedented climate change, this study analyzed the variability, trends, and occurrence of extreme rainfall events in Goiânia between 1961 and 2023. By using daily and monthly data compiled from the National Meteorological Institute's conventional station, this study investigated the behavior of annual, seasonal, and monthly rainfall variability and evaluated trends and the occurrence of extreme events based on statistical indices. The data points to a usual concentration of rainfall in seven months and an inherent annual and seasonal variability in rainfall, which is altered from time to time in exceptionally dry or rainy years. There is also the possibility of a greater occurrence of extreme daily events and an increase in the period of drought, leading to recurring problems for the population.

Keywords: Rainfall. Climate Change. Rainfall Impact.

Resumo: Apesar de Goiânia ser uma cidade relativamente jovem e de médio porte, tem enfrentado recorrentes problemas causados tanto pelo excesso quanto pela escassez das chuvas. Diante do contexto das mudanças climáticas generalizadas, aceleradas e sem precedentes históricos, o presente trabalho analisou a variabilidade, as tendências e a ocorrência de eventos extremos de precipitação em Goiânia, no período compreendido entre 1961 e 2023. A partir de dados diários e mensais compilados da estação convencional do Instituto Nacional de Meteorologia, averiguou-se variabilidade anual, sazonal e mensal das chuvas e avaliaram-se as tendências e ocorrência de eventos extremos com base em índices estatísticos. Os dados apontam para uma concentração habitual das chuvas em sete meses e uma variabilidade anual e sazonal inerente às chuvas, que ora ou outra é alterada no contexto de anos excepcionalmente secos ou chuvosos. Além disso, constata-se a hipótese de maior ocorrência de eventos diários extremos e de aumento do período de estiagem, condicionando recorrentes problemas para a população.

Palavras chave: Chuvas. Mudanças Climáticas. Impacto Pluviométrico.

Resumen: Aunque Goiânia es una ciudad relativamente joven y de tamaño medio, se ha enfrentado a problemas recurrentes causados tanto por el exceso como por la escasez de precipitaciones. En el contexto de un cambio climático generalizado, acelerado e históricamente sin precedentes, este estudio analizó la variabilidad, las tendencias y la ocurrencia de eventos de precipitación extrema en Goiânia entre 1961 y 2023. Utilizando datos diarios y mensuales compilados a partir de la estación convencional del Instituto Meteorológico Nacional, se investigó el comportamiento de la variabilidad anual, estacional y mensual de las precipitaciones, y se evaluaron las tendencias y la ocurrencia de eventos extremos a partir de índices estadísticos. Los datos apuntan a una concentración habitual de las precipitaciones en siete meses y a una variabilidad anual y estacional inherente a las lluvias, que se ve alterada de vez en cuando en el contexto de años excepcionalmente secos o lluviosos. También existe la posibilidad de una mayor ocurrencia de eventos diarios extremos y un aumento del periodo de sequía, lo que conlleva problemas recurrentes para la población.

Palabras clave: Precipitaciones. Cambio climático. Impacto de las precipitaciones.

> "Oh! Chuva.
> Eu peço que caia devagar
> Só molhe esse povo de alegria
> Para nunca mais chorar"
> (Compositor: Luis Carlos Xavier Ewald; música: Falamansa, 2021)

Introduction

The significant urban growth and the intensification of anthropogenic activities have led to various changes in urban spaces, notably impacting the climate system. In this context, the city emerges as an environment in constant transformation and adaptation, particularly due to modifications in the radiation balance (CHAVES et al., 2022).

In urbanized environments, climatic parameters vary depending on the configuration, structure, and type of surface covering, with notable effects on temperature differences, relative humidity variation, and the intensity of precipitation events between central (more urbanized) areas and the peripheral regions (SILVA et al., 2016).

Monteiro (1976) established a fundamental theoretical and methodological framework for studying the urban climate, known as the "Urban Climate System" (UCS), which describes the specific climatic organization of urban spaces. According to the author, the urban climate comprises three interrelated and integrated subsystems: the thermodynamic subsystem, related to thermal comfort; the physicochemical subsystem, associated with air quality; and the hydrometeorological subsystem, which encompasses extreme precipitation events and their impacts. This study will focus on this last subsystem.

The historic drought in the Amazon in 2023, as well as the extreme rainfall events in the Northeast that same year and in Rio Grande do Sul in 2024, are indicators of an ongoing climate change process—one that is unequivocal, widespread, accelerated, irreversible, and with no historical precedents (IPCC, 2021). Evidence of such climate change can be observed on a global scale, with broad impacts on environmental, social, economic, and cultural systems.

However, extreme climate events are not exclusive to recent years, as demonstrated by Ribeiro (2008), Marengo (2009), Aleixo et al. (2010), and Artaxo (2014). What underscores the seriousness of the current global climate crisis is the increasing frequency, intensity, and severity of these events.

Specifically in the context of Brazil's Central-West region, future scenarios presented in the IPCC's Sixth Assessment Report (2021) indicate a hotter and drier climate, with possible changes in the rainfall regime—especially regarding the extension and intensity of dry periods and the occurrence of extreme events. This scenario is supported by Almeida (2021) and Santos et al. (2023), as well as by Hofmann et al. (2021) and Rodrigues et al. (2020) concerning the Cerrado biome, by Neves (2018) and Deus and Nascimento (2021) for the state of Goiás, and by Luiz (2012), Nascimento, Lima, and Cruz (2019) and Silva and Nascimento (2021) specifically for the city of Goiânia.

Although a relatively young and mid-sized city, Goiânia has faced recurrent issues related to both excessive and insufficient rainfall. In the first case, extreme precipitation events frequently disrupt urban mobility, cause flooding and inundations, lead to material damage, and, in some cases, result in loss of life (REGO & BARROS, 2014; LUIZ & ROMÃO, 2019). On the other hand, drought periods compromise water availability for the population. It is important to note that the residents of Goiânia experience alertness, anxiety, and panic not only during dry spells but also throughout the rainy season, precisely due to extreme precipitation events.

Therefore, the main objective of this study is to describe precipitation patterns in Goiânia, Goiás, from 1961 to 2023 (63 years) while analyzing annual, seasonal, and monthly variability and identifying extreme events in order to understand rainfall trends and patterns and their social, economic, and environmental impacts.

Methodology

Location and brief characterization of the study area

Goiânia, capital of the state of Goiás, is located between 16°27′1″ and 16°49′55″ south latitude and 49°4′37″ and 49°27′1″ west longitude. The city is located in Brazil's Central-West region and has a population of 1,437,366 inhabitants, according to the 2022 Demographic Census conducted by the Brazilian Institute of Geography and Statistics. Goiânia covers a territorial area of 729.29 km², of which 309.57 km² (42%) correspond to the urban area, according to MapBiomas (2022) – Figure 1.

According to Nascimento and Oliveira (2011), Goiânia's urban area experienced an irregular and accelerated expansion between 1986 and 2010, growing from 144 km² to 278 km², nearly doubling in size. Pereira, Nascimento, and Oliveira (2012) add that an intense verticalization process occurred from the 1960s to the 1990s, particularly in the central and southern parts of Goiânia. Regarding the urbanization process, Streglio, Nascimento, and Oliveira (2013) highlight that between 1980 and 1990, natural vegetation was converted into agricultural and livestock activities, especially in the city's northern and northwestern areas.

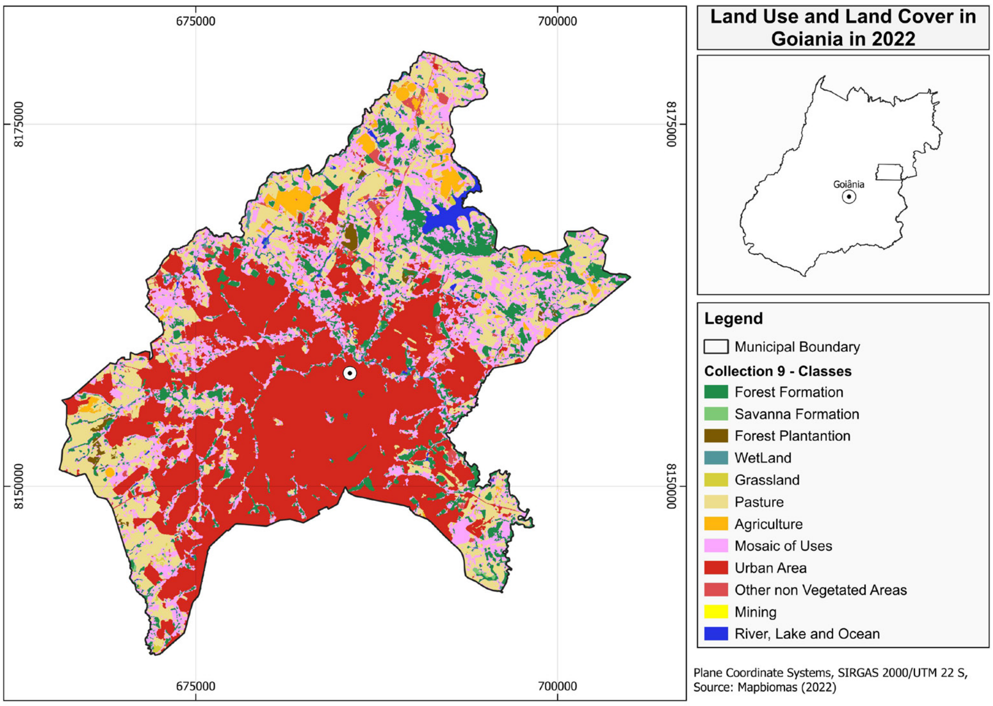

Figure 1 – Land Use and Land Cover in Goiânia, 2022

Source: MapBiomas (2022), compiled by the authors.

According to the Köppen-Geiger climate classification, Goiânia has a tropical semi-humid climate (classified as Aw), with two well-defined seasons: a rainy season (October to April) and a dry season (May to September) (CARDOSO; MARCUZZO; BARROS, 2014). Tropical climates are characterized by high temperatures throughout the year. Based on climate normals from 1991 to 2020, Goiânia has an average annual temperature of 24.5 °C. The hottest quarter occurs from August to October, while the one from June to August has the lowest average temperatures – Figure 2.

The semi-humid regime is reflected in the concentration of rainfall between October and April, which accounts for 94.1% of the average annual precipitation of 1,610 mm, based on 1991–2020 climate normals. The wettest quarter includes the months of December, January, and February—summer months—with December being the rainiest month, averaging 271.9 mm. The dry season, from May to September, has the lowest precipitation levels, with July being the driest month, whose monthly average is less than 10 mm.

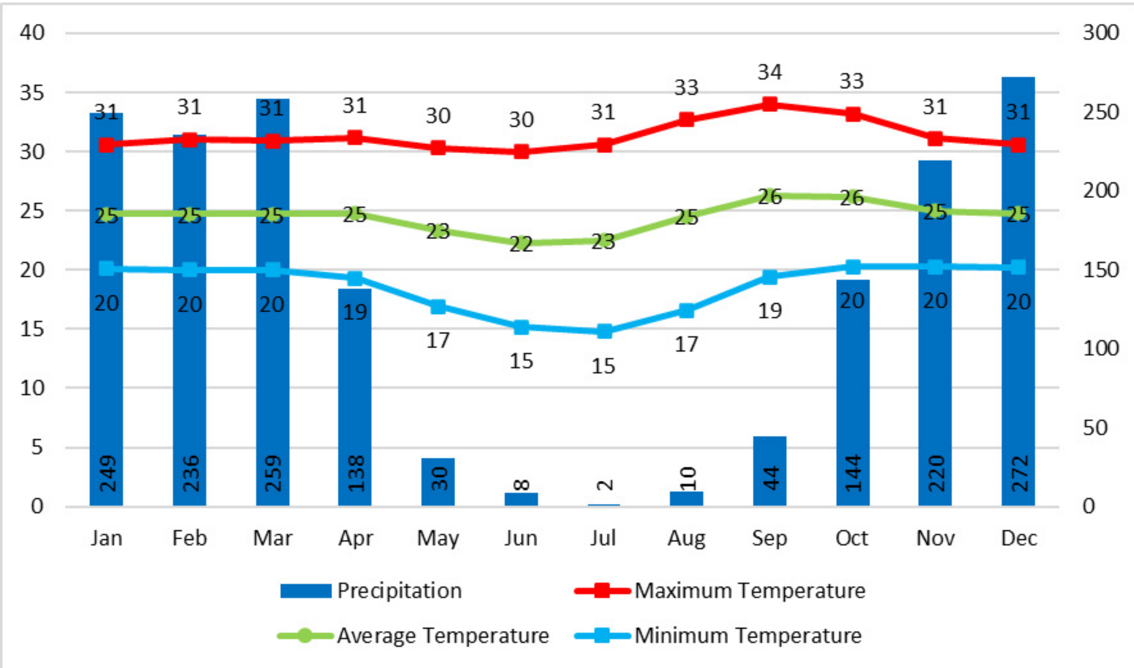

Figure 2 – Climograph showing monthly averages of precipitation and maximum, mean, and minimum temperatures for the conventional weather station in Goiânia (1991–2020)

Source: INMET climate normals (1991–2020), compiled by the authors.

Luiz (2012) and Nascimento and Oliveira (2020) explain that the latitudinal and continental location of the study's area influence its thermal characteristics. The concentration of rainfall within seven months reflects the predominance of the continental equatorial air mass, which originates over the Amazon Rainforest and is responsible for transporting moisture to the rest of the country. This contrasts with the continental tropical air mass, which prevails during the dry season.

Methodological procedures

This study structured the methodological procedures adopted into six stages. The initial stage involved a literature review covering various types of publications (articles, undergraduate theses, dissertations, doctoral theses, and books) related to urban climate, rainfall variability, climate change, and extreme events.

The next stage involved collecting monthly and daily precipitation data recorded between 1961 and 2023 at the conventional weather station in Goiânia, operated by the National Institute of Meteorology. The station is located in Goiânia's Central Sector, at coordinates 16°40'22" south latitude and 49°15'49" west longitude, in a highly urbanized area with a high volume of people and vehicle traffic. The collected data was organized into Excel spreadsheets for further statistical analysis and graphical representation.

The first analysis focused on evaluating monthly, seasonal, and annual rainfall variability in Goiânia, using Schroeder's pluviogram (1956) and following the guidelines of Nascimento, Pessoa-de-Souza, and Silva (2019). Subsequently, based on daily precipitation data, this study calculated standardized indices developed by the Expert Team On Climate Change Detection, Monitoring and Indices (ETCCDMI), affiliated with the World Meteorological Organization (WMO). Table 1 lists all the seven indices used in this study, all related to the precipitation parameter. These indices were applied to detect extreme events and trends within the time series. For more information on the formulation and description of these indices, see Karl, Nicholls, and Ghazi (1999), Peterson et al. (2001), and Peterson (2005).

Table 1 – Extreme event indices used in this study

Sigla	Nome	Descrição	Unidade
PRCPTOT	Total Precipitation	Annual total precipitation	mm
RX1day	Maximum 1-day precipitation amount	Highest daily precipitation volume	mm
Rx5day	Maximum 5-day precipitation amount	Highest five-day precipitation volume	mm
R10mm	Number of heavy precipitation days	Number of days per year with precipitation > 10 mm	Days
R20mm	Number of very heavy precipitation days	Number of days per year with precipitation > 20 mm	Days
CDD	Consecutive Dry Days	Maximum number of consecutive days with precipitation < 1 mm	Days
CWD	Consecutive Wet Days	Maximum number of consecutive days with precipitation > 1 mm	Days

Source: Compiled by the authors.

The indices were calculated using the Climpact interface, developed by the Open Panel of Experts on Climate Information for Adaptation and Risk Management (OPACE 4), which is also affiliated with the WMO. The interface, based on the R programming language and third-party packages, is available at https://ccrc-extremes.shinyapps.io/climpact/.

Trend analysis was conducted by observing the slope of the linear regression curve (Sen's slope), emphasizing the trend's direction (positive or negative). In addition, the trend's statistical significance was assessed, considering p-values between 0.1 and 0.05 moderately significant and those below 0.05 highly significant—according to the guidelines of Santos and Brito (2007).

Finally, this study compiled news articles from major newspapers in the state of Goiás to examine the social, economic, and environmental impacts of rainfall variability and extreme precipitation events in Goiânia. The search used keywords such as "rain," "precipitation," "storm," "drought," "dry spell," and related terms without specific time constraints. The most frequently recurring articles over the years were selected, focusing on the systematic consequences associated with dry periods and extreme events.

Results and Discussion

This section presents the study's main findings and related discussions. It begins by analyzing rainfall variability in Goiânia between 1961 and 2023, followed by an examination of trends and extreme events. Finally, it contextualizes the social, economic, and environmental repercussions of rainfall variability, trends, and extremes in Goiânia based on newspaper articles.

Annual, Seasonal, and Monthly Rainfall Variability in Goiânia (1961–2023)

The pluviogram in Figure 3 shows the interannual and intra-annual variability of rainfall in Goiânia, displaying monthly and annual precipitation totals from 1961 to 2023. Data gaps were observed only in 1979 and 1981, which were excluded from the analysis. The average annual rainfall for this period is 1,600 mm, with values ranging from a minimum of 1,064 mm (1963) to a maximum of 2,147 mm (2021), resulting in an amplitude of 1,083 mm.

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total annual
1961	364	258	173	31	18	0	0	0	0	109	215	248	1355
1962	180	160	290	62	45	0	0	0	10	281	180	239	1448
1963	259	282	64	88	17	0	0	0	17	32	168	138	1064
1964	351	248	101	113	56	0	2	0	92	272	182	205	1622
1965	336	114	199	148	16	41	0	1	75	402	160	207	1697
1966	266	276	187	94	64	0	0	5	32	125	138	426	1611
1967	233	167	259	138	0	3	0	0	13	118	228	216	1374
1968	255	389	112	98	6	8	0	19	10	129	192	247	1465
1969	335	161	232	68	30	0	0	0	7	171	405	291	1700
1970	281	235	239	128	14	2	0	2	62	218	336	97	1613
1971	140	261	267	97	39	11	11	0	64	244	294	331	1758
1972	229	262	167	112	41	0	11	48	33	148	310	361	1722
1973	310	198	217	155	44	11	0	0	8	230	252	249	1673
1974	128	141	326	226	48	1	0	33	1	87	110	206	1307
1975	203	217	136	183	18	1	15	0	53	162	249	206	1443
1976	149	157	295	72	113	16	3	4	148	143	337	302	1738
1977	322	152	120	186	125	51	0	15	65	189	170	154	1550
1978	277	287	222	126	45	0	26	0	58	82	152	218	1492
1980	541	404	56	29	3	40	0	7	95	80	179	235	1668
1982	318	138	424	145	75	0	2	37	56	264	150	441	2049
1983	348	184	232	201	26	6	27	0	47	145	303	252	1771
1984	186	197	250	194	33	0	0	38	61	133	117	265	1474
1985	442	153	237	148	1	0	4	0	55	244	225	241	1750
1986	231	188	97	61	22	0	9	74	27	49	178	335	1269
1987	277	115	222	179	19	0	0	1	64	195	221	373	1664
1988	203	338	225	222	13	52	0	0	18	152	122	208	1551
1989	166	245	194	24	3	13	27	54	86	153	216	480	1660
1990	206	90	250	86	72	0	4	22	32	142	243	218	1365
1991	301	237	277	169	3	0	0	0	77	131	89	252	1534
1992	257	229	208	169	16	0	0	0	126	369	214	336	1924
1993	132	250	201	43	17	38	0	59	44	178	220	316	1498
1994	338	185	304	68	18	29	9	0	5	112	297	247	1610
1995	278	208	399	174	82	4	0	0	12	104	185	249	1694
1996	214	174	320	239	21	1	0	44	55	309	215	172	1763
1997	269	187	425	123	55	76	0	7	33	64	212	147	1596
1998	246	326	264	70	21	0	0	4	41	146	256	201	1574
1999	197	188	119	28	67	7	0	0	71	175	201	296	1348
2000	386	320	207	45	9	0	1	32	106	84	328	316	1834
2001	209	227	182	172	72	2	0	52	125	185	315	228	1767
2002	254	398	300	28	12	0	0	6	70	34	150	285	1536
2003	315	268	202	108	0	0	0	13	35	111	265	224	1541
2004	282	310	264	120	18	1	6	0	6	168	129	251	1556
2005	238	176	526	50	34	3	0	3	56	91	270	460	1907
2006	138	217	319	206	20	0	0	11	84	283	188	238	1705
2007	200	267	87	60	9	5	6	0	2	56	223	180	1095
2008	281	294	374	202	53	0	0	0	52	109	198	246	1809
2009	179	148	186	258	41	31	2	17	71	196	195	444	1768
2010	98	208	190	188	0	14	0	0	17	108	282	450	1556
2011	288	240	367	62	0	15	0	0	1	300	245	293	1813
2012	467	358	268	176	40	18	3	0	57	93	225	189	1894
2013	354	125	235	44	44	7	0	1	33	135	274	531	1782
2014	144	188	361	325	20	0	16	0	31	69	171	338	1662
2015	74	225	312	204	71	0	3	4	30	18	355	208	1503
2016	485	155	156	1	33	0	0	16	27	209	110	170	1362
2017	176	153	216	200	48	0	0	0	10	51	296	239	1389
2018	207	289	157	225	13	0	0	19	32	224	186	190	1540
2019	143	196	192	213	52	0	0	0	19	83	161	219	1277
2020	329	327	152	157	21	0	0	0	2	122	161	307	1576
2021	250	418	276	137	0	0	0	5	62	246	358	396	2147
2022	315	438	101	51	2	0	0	0	31	109	216	348	1611
2023	322	237	172	165	0	5	0	28	29	106	157	277	1498
Maximum	541	438	526	325	125	76	27	74	148	402	405	531	2147
Minimum	74	90	56	1	0	0	0	0	0	18	89	97	1064
Average	261	232	232	129	32	8	3	11	45	156	220	273	1600

Figure 3 – Annual and Monthly Rainfall Variability in Goiânia (1961–2023)

Source: INMET, compiled by the authors. Note: 1979 and 1981 had missing data.

Typically, the rainy season in Goiânia begins in October and extends through April, totaling seven rainy months. The dry season runs from May to September, as Nimer (1979) and Monteiro (1951) indicated for the region. However, changes at the start and/or end of the rainy season occur in certain years, which leads to variations in the length of both the rainy and dry periods. For example, in 1961, 1962, 1993, 2011, 2016, and 2022, the dry season began earlier in April, prolonging the dry period to six months. In other years, such as 1963 and 1986, the dry season also started in April, as usual, but extended until October. Conversely, in 1966 and 1976, the dry season lasted only three months (June to August), while in 1977, it was reduced to just two months (July and August) due to significant rainfall in the preceding and following months.

This variability is a characteristic of rainfall patterns, which are influenced not only by changes in annual totals during wetter or drier years but also by interannual distribution. Luiz (2012), Nascimento (2016), and Neves (2018) note that the stronger or weaker influence of atmospheric systems responsible for precipitation, such as the continental equatorial air mass and the South Atlantic Convergence Zone, can explain the variations in annual totals and monthly distribution, as demonstrated by Nascimento and Oliveira (2021). A case in point is the year 2007, which recorded only 1,095 mm of rainfall and five dry months. The authors classify this as a dry-pattern year, marked by the predominance of the tropical Atlantic air mass, which increases atmospheric stability and reduces precipitation formation.

It is also important to highlight the influence of atmospheric phenomena that affect the region’s rainfall regime, such as the South Atlantic Dipole, the Southern Annular Mode (SILVA; CARPENEDO, 2021), the El Niño-Southern Oscillation (ENSO), and the Pacific Decadal Oscillation (PDO) (ALVES; CABRAL; NASCIMENTO, 2022; 2023).

Figure 3 also shows that December and January are the wettest months, with average precipitation of 272.5 mm and 260 mm, respectively. Over the time series, record rainfalls were observed in January 1980 (540.8 mm) and December 2013 (530.5 mm). Conversely, the driest consecutive three-month period is June to August, with July being the driest month.

Typically, the dry season includes two consecutive months without precipitation (as seen in 1966, 1967, 1973, 1988, 1992, 1995, 1999, 2003, 2006, 2010, 2011, 2016, 2018, and 2022), but it may also last for three months (1963, 1969, 1991, 2008, 2017, 2020, and 2021) or even four months (1961). This is a characteristic of the central Cerrado biome, as noted by Nascimento and Novais (2020). However, contrary to popular belief and frequent media portrayals, rainfall can occur during the dry season, as demonstrated by records of 76.4 mm in June 1997, 27.2 mm in July 1983, and 73.9 mm in August 1986.

Trends and Extreme Precipitation Events in Goiânia Between 1961 and 2023

The analysis of rainfall trends begins by assessing the total annual precipitation index (PRCPTOT), which shows a positive trend for Goiânia (Sen's slope of 1.164). However, the graph in Figure 4 reveals low statistical significance (p-value = 0.43). Silva and Nascimento (2021) saw a similar situation for Goiânia. By analyzing the same index for different locations in the Central-West region, Almeida (2012) also found a positive trend in most stations in Goiás, including Goiânia, although with low statistical significance.

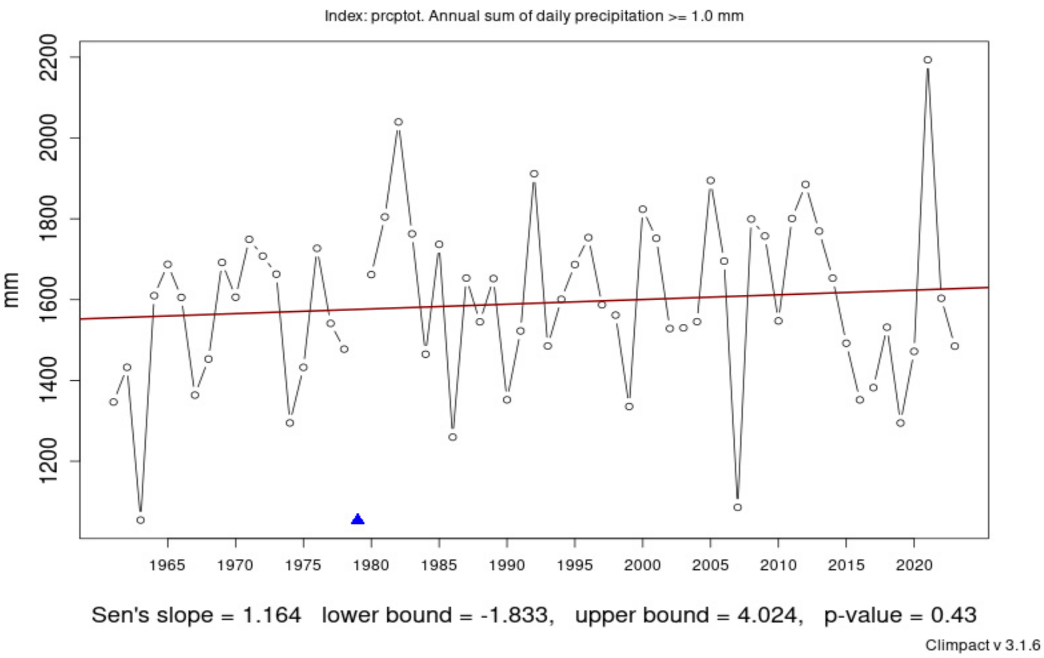

Figure 4 – PRCPTOT – Total Annual Precipitation (1961–2023)

Source: INMET, organized by the authors

The maximum one-day (Rx1day) and five-day (Rx5day) precipitation indices also show positive trends. Both indices are represented in Figures 5 and 6, respectively. However, only the Rx1day index shows high statistical significance, with a p-value of 0.032. These indices reflect extreme precipitation values, such as the 136 mm value recorded in a single day in December 2005, 134 mm in December 1972, and 127.8 mm in October 1996. Nascimento, Lima, and Cruz (2019) explain that extreme rainfall episodes in Goiânia are associated with the alternating activity of the Amazonian Equatorial Continental air mass and the South Atlantic Convergence Zone.

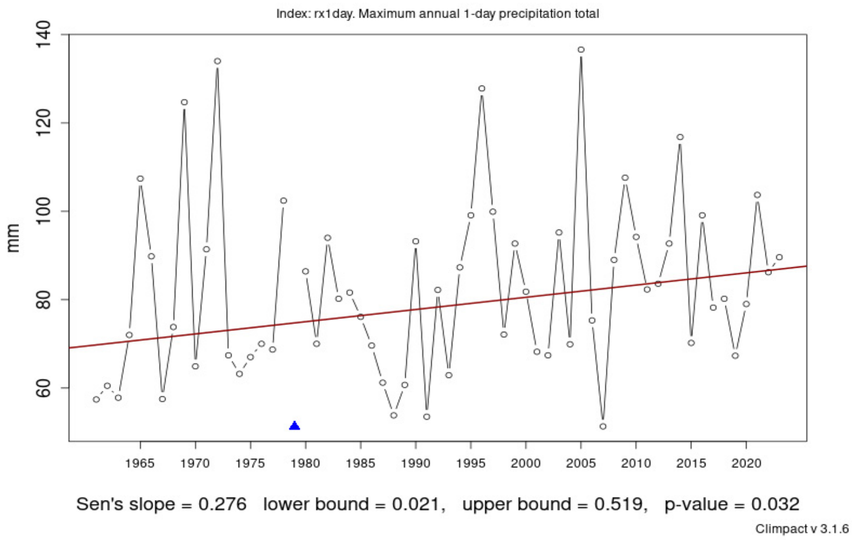

Figure 5 – Rx1day – Maximum One-Day Precipitation (1961–2023)

Source: INMET, organized by the authors

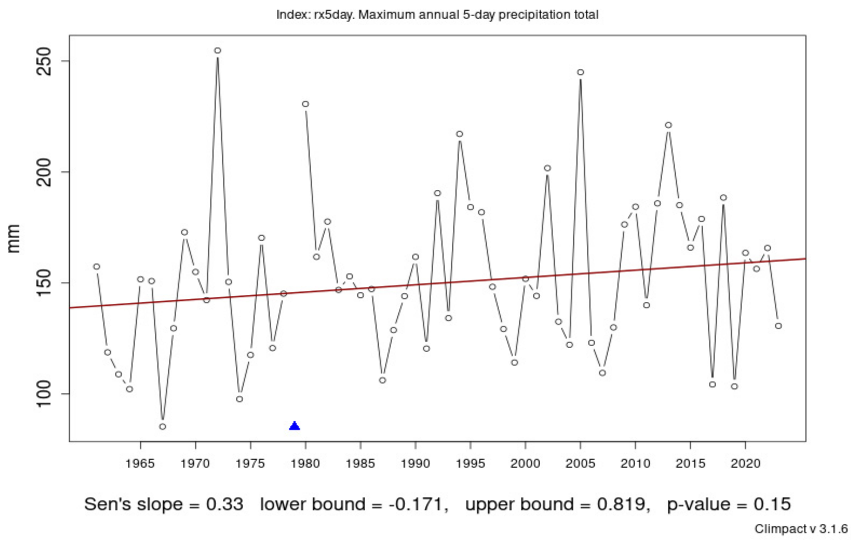

Figure 6 – Rx5day – Maximum Five-Day Consecutive Precipitation (1961–2023)

Source: INMET, organized by the authors

Regarding the Rx5day index, extreme events include 254.8 mm in December 1972, 245 mm in December 2005, and 230.7 mm in January 1980. These episodes are often associated with the persistence of the South Atlantic Convergence Zone, which is more intense between November and February and can last four to ten days (Nascimento & Neves, 2021).

These two indices present a concerning scenario for Goiânia, as extreme precipitation over consecutive days leads to a series of issues such as soil saturation, increased surface runoff, triggering of erosion processes, and sedimentation of water bodies. Additionally, the risk of floods, inundations, and waterlogging increases, as Luiz (2012), Rego and Barros (2014), Evangelista et al. (2016), and Luiz and Romão (2019) observed for this city.

Figure 7 shows that the index for the number of days with precipitation above 10 mm (R10mm) does not present a significant trend over the analyzed period, reinforcing rainfall variability. Among extreme records, some that stand out are 69 days with precipitation above 10 mm in 1982, 64 days in 1992 and 2011, and 63 days in 2021.

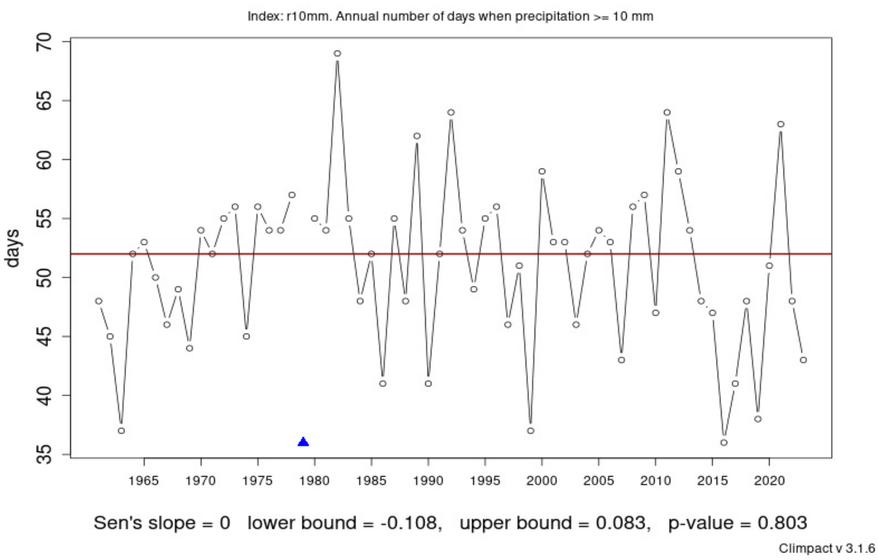

Figure 7 – R10mm – Number of Days with Precipitation Above 10 mm (1961–2023)

Source: INMET, organized by the authors

Unlike R10mm, the index for the number of days with precipitation above 20 mm (R20mm) shows a slight positive trend, although not statistically significant (Figure 8). Despite this, some years recorded extremes of up to 38 days with precipitation above 20 mm in 2021, 35 days in 1981 and 1982, and 33 days in 1980, 1985, 1992, and 1996. Such rainfall events have a high potential of causing damage, as volumes exceeding 10 mm are already sufficient to cause disturbances in Goiânia, as emphasized by Luiz (2012).

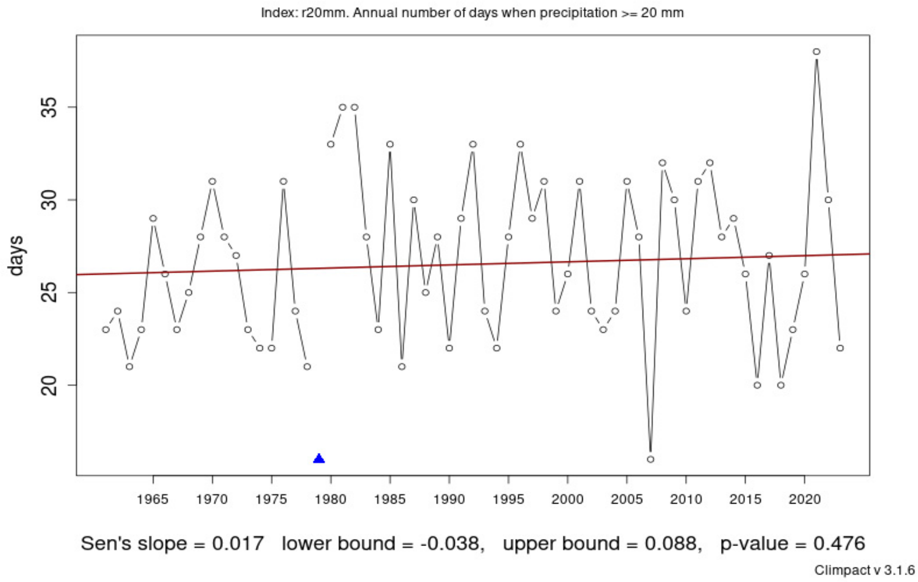

Figure 8 – R20mm – Number of Days with Precipitation Above 20 mm (1961–2023)

Source: INMET, organized by the authors

As represented in Figure 9, there is a positive trend with good statistical significance (p-value of 0.08) for the number of consecutive dry days per year (CDD). In other words, consecutive periods without rainfall in Goiânia have increased over the analyzed period. In the first two decades, the trend is negative, despite such period having the highest values, reaching up to 156 consecutive dry days in 1961, 138 days in 1963, and 135 days in 1969. After the 1980s, the trend for this index is positive, with extreme records such as 133 consecutive dry days in 2008. On the other hand, there are extreme records of the lowest number of consecutive dry days in a year, with only 29 and 31 days in 1976 and 1971, respectively—indicating years with a more regular rainfall distribution.

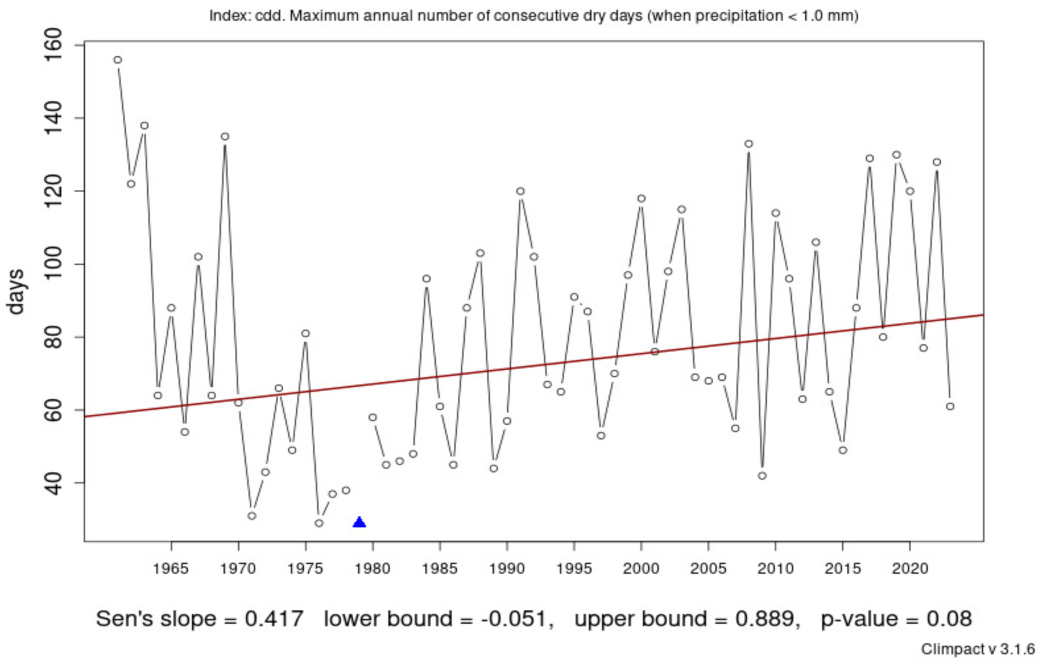

Figure 9 – CDD – Consecutive Dry Days (1961–2023)

Source: INMET, organized by the authors

Based on the literature, Nascimento and Novais (2020) explain that the dry season in the region results from the predominant influence of the Tropical Atlantic air mass, which promotes atmospheric stability, clear skies, and the absence of precipitation events.

As for the index of consecutive wet days (CWD), a positive trend can be noted, although without statistical significance (Figure 10). Regarding the highest values of consecutive days with precipitation, this study highlights the years 1982, with 18 days; 1987 and 2016, with 17 days; and 1988, 2020, and 2021, with 16 days. Although they do not last as long as consecutive dry days, consecutive rainy days are also concerning, particularly considering how they contribute to soil saturation and increased surface runoff, with negative repercussions for sediment transport and flood occurrence.

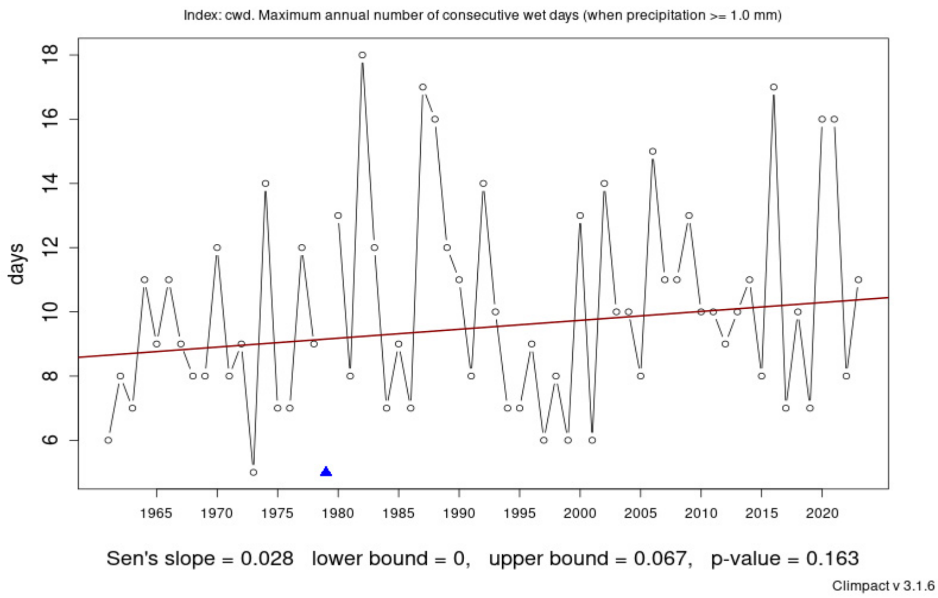

Figure 10 – CWD – Consecutive Wet Days (1961–2023)

Source: INMET, organized by the authors

The information presented in this section is summarized in Table 2 and it indicates positive trends in changes to rainfall in Goiânia for almost all the analyzed indices, except for the number of days per year with precipitation equal to or above 10 mm (R10mm). However, only the indices of maximum one-day precipitation (Rx1day) and number of consecutive dry days (CDD) show statistical significance. Thus, the increase in extreme rainfall events and the lengthening of dry periods is evident, which corroborates the scenario of changing rainfall patterns described by the IPCC (2021) and by studies such as Hoffmann et al. (2021), Almeida (2021), Luiz (2021), Neves (2018), among others, either for the studied area or the broader region.

Table 2 – Summary of Climate Change Trends and Occurrence of Extreme Precipitation Events in Goiânia (1961 to 2023)

Index	Trend	Significance	Extreme events/Year
PRCPTOT	1.164 (positive)	0,430	2,147.4 mm (2021)
RX1day	0.276 (positive)	0.032 (high)	136 mm (2005)
Rx5day	0.330 (positive)	0.150	254.8 mm (1972)
R10mm	0 (none)	0.803	69 Days (1982)
R20mm	0.017 (positive)	0.476	38 Days (2021)
CDD	0.417 (positive)	0.080 (good)	156 Days (1961)
CWD	0.028 (positive)	0.163	18 Days (1981)

Source: Author

This scenario of more concentrated and intense rainfall over a shorter time span is extremely concerning, as it results in undesirable repercussions in the social, economic, and environmental spheres, as it will be discussed in the following section.

Impacts of rainfall in Goiânia as illustrated by news reports

The population of Goiânia frequently faces problems due to both lack and excess of rainfall. While drought causes water, food, and energy insecurity, affecting the economic and productive sectors, the main impacts of extreme precipitation events are flooding, inundation, waterlogging, internal mobility problems, material and infrastructure damage, and life loss.

The lack of rainfall during the dry season in Goiânia compromises water availability, food production, and electricity generation, resulting in water, food, and energy insecurity. A recurring issue for the population of Goiânia is the interruption of water supply during the dry season, as Figure 11 shows.

Although Goiânia typically experiences a five-month dry season, there is a lack of public adaptation policies and action plans to address the recurring effects of drought, especially in exceptionally dry years, when the dry season may begin earlier, extend later, or last longer (as evidenced by the climograph in Figure 3). The "hydro-illogical" cycle proposed by Wilhite (2011) illustrates how the alertness, anxiety, and panic among the population and public managers during droughts is often replaced by apathy and complacency once the rains return (Figure 12), without implementing effective public policies.


Moradores de Goiânia e região pedem socorro por causa da falta d'água

Saneago informou que pode faltar água em mais de 200 bairros da Grande Goiânia neste fim de semana e que problema é causado pela baixa vazão do Rio Meia Ponte

Frank Martins
28 de outubro de 2017 às 15:00
Modificado em 29/08/2023, 08:23

Falta de água atinge até mesmo unidades de saúde como a Maternidade Marlene Teixeira, em Aparecida (Marcello Dantas)

Figure 11 – Report on residential water supply interruption in Goiânia in 2017

Source: O Popular

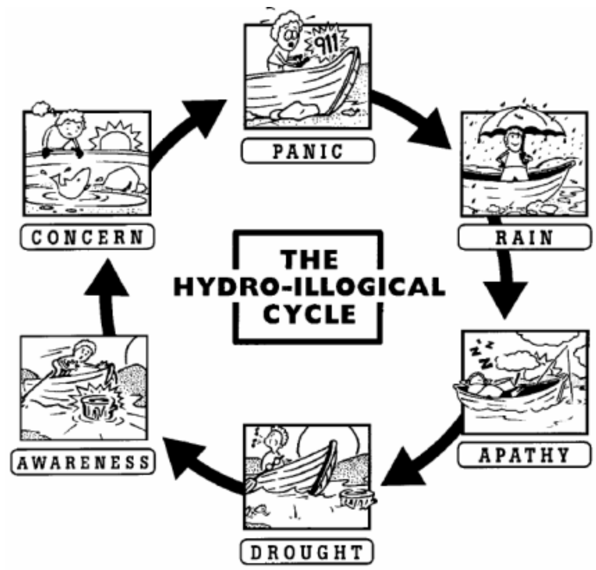

Figure 12 – The "hydro-illogical" cycle

Source: Adapted from Wilhite (2011)

Rainfall irregularity is a major concern in the agricultural sector, disrupting the farming calendar and causing production losses. The CDD index (Figure 9) indicates an increase in the dry season, which may further impact this sector. In addition to the economic losses suffered by agricultural producers across the state of Goiás (Figure 13), the population of Goiânia often faces food insecurity, especially due to rising food prices during periods of drought.

Figure 13 – Impact of the 2015 drought on agriculture

Source: Jornal Opção

In Goiânia, rainfall influences flooding, inundation, and waterlogging, as well as related issues caused by runoff. **Figure 14** illustrates the urban mobility problems caused by extreme precipitation events in Goiânia.

Figure 14 – (A) Flooding on Marginal Botafogo on 11/26/2015 and (B) Flooding on highway GO-060 near Trindade on 04/04/2024

Source: (A) O Popular (B) O Popular

Figure 14-A shows one of the areas most prone to flooding in Goiânia: Marginal Botafogo, which is regularly inundated due to the channeling of the watercourse and the large volume of surface runoff from adjacent areas. In turn, Figure 14-B illustrates flooding and mobility issues caused by soil sealing, which hinders or prevents water infiltration.

Luiz and Romão (2019) explain that episodes of intense rainfall at the beginning and peak of the rainy season are especially concerning due to the behavior of unsaturated tropical soils. Rego and Barros (2014) provide a historical account of such events in Goiânia between 1996 and 2010, based on civil defense reports and news articles. They highlight the years 2009 and 2005 as those with the highest number of floods and inundations, with the Setor Bueno, Jardim Guanabara II, and Jardim América being the most affected neighborhoods.

In addition to mobility issues, extreme weather events also cause considerable material damage, especially the intrusion of rainwater or water from watercourses into homes and the falling of trees. Figure 15-A illustrates property damage, while Figure 15-B shows structural damage to the power grid due to tree falls, which endanger the population.

A


Chuva causa estragos em bairros de Goiânia

Ao menos duas quedas de árvores foram registradas na capital. No Jardim Planalto, outdoor caiu sobre duas lojas

Carol Almeida
7 de outubro de 2019 às 19:09
Modificado em 21/04/2023, 22:03

Atualizado às 19h31

Mesmo breve, a chuva que caiu sobre alguns bairros da capital na tarde desta segunda-feira (7) provocou danos em algumas localidades. Ao menos duas quedas de árvores foram registradas em Goiânia. No Setor Jardim América, na Região Sul da capital, um veículo que estava estacionado na Rua C-143 foi atingido. Já na Rua T-17 A, no Setor Aeroporto, na Região Central, um espécime de grande porte caiu sobre a via e teve o tronco retirado por uma equipe da Companhia de Urbanização de Goiânia (Comurg). Em nenhum dos casos houve feridos.

B


Chuva derruba 78 árvores e deixa bairros sem energia, em Goiânia

Bairros da região noroeste e leste da capital foram os mais afetados pela tempestade, que registrou rajadas de ventos de até 60 km/h

Augusto Sobrinho
29 de novembro de 2022 às 14:59

Rua J-60, Setor Jaó, em Goiânia (Graça Castro/Arquivo Pessoal)

Figure 15 – (A) Material damage caused by rain and (B) impacts on the power grid due to falling trees in Goiânia

Sources: (A) O Popular (B) O Popular

One of the most severe consequences of extreme rainfall events in Goiânia has been the loss of human lives. In this regard, Figures 16-A and 16-B present news reports on the deaths of motorcyclists swept away by flash floods during heavy rains in January 2018 and 2023, respectively.

Figure 16-C reports an intense rainfall event of 100 mm in six hours in Goiânia, which caused the collapse of an improvised home located in a permanent preservation area of the Cascavel stream, resulting in the death of one person.

A

ÚLTIMAS NOTÍCIAS

Homem morre após ser levado por enxurrada em Goiânia

Larissa Quixabeira | 30 janeiro 2018 às 08h31

Motociclista se desprendeu da moto com a força da água durante a forte chuva que caiu na capital na última segunda-feira (29)

Foto: Alexandre Parrode

B

Corpo de motociclista arrastado por enxurrada durante temporal é encontrado em Goiânia

Warley Melo Adorno, de 22 anos, estava desaparecido desde a tarde de segunda-feira. Bombeiros precisaram usar drones e mergulhadores durante buscas.

Por Thauany Melo, g1 Goiás
31/01/2023 08h01 · Atualizado há um ano

C

Morto após temporal em Goiânia trabalhava com recicláveis

Capital recebeu mais de 100 mm de chuvas em seis horas provocando a elevação rápida dos níveis dos mananciais. Desmoronamento de barraco em área de risco matou um homem

Malu Longo
31 de dezembro de 2023 às 18:45
Modificado em 31/12/2023, 21:34

Tubulação na Vila Roriz: moradores afirmam que máquina a servio da Saneago fez intervenção recente em rua (Fábio Lima)

Figure 16 – (A) Death caused by flash flooding in 2018, (B) in 2023, and (C) landslide in 2023

Sources: (A) Jornal Opção (B) G1 (C) O Popular

Thus, it is essential to emphasize that extreme rainfall events not only damage urban infrastructure but also compromise social well-being, particularly the right to mobility. Therefore, actions are needed to mitigate the effects of climate change and the damages caused by extreme climate events, many of which can be predicted, minimized, or even avoided. It is essential that different levels of government develop and implement public policies to reduce the effects of climate change, promoting urban resilience and a better quality of life for the population, as more intense events can result in fatalities and significant losses.

However, in the case of Goiânia, Souza and Nascimento (2018) point out that the main adaptation measure is installing warning signs in areas prone to flooding, aiming to prevent traffic in those areas during heavy rains.

The last news item in Figure 16-C shows that the climate crisis does not affect all territories and populations equally. The population living in the peripheral areas of Goiânia suffers more significant impacts from intense rainfall events due to higher vulnerability, lack of infrastructure, and limited support from public authorities. Therefore, public policies related to climate adaptation must incorporate social justice and inclusion, especially targeting the most vulnerable groups.

Final Considerations

Goiânia has a semi-humid tropical climate characterized by a seven-month rainy season (from October to April) and a five-month dry season (from May to September), with an average annual precipitation of about 1,600 mm. However, considerable variability in precipitation between 1961 and 2023 was observed, with annual totals ranging between 1,064 and 2,147 mm and fluctuations in the period and duration of the dry season.

The analysis of rainfall precipitation indices reveals positive trends, although with variable statistical significance. Specifically, a statistically significant trend of increased extreme precipitation events is observed, represented by the Rx1day index, which points to a worrying scenario regarding urban impacts in Goiânia, such as floods, inundations, and erosion. Similarly, a trend of increased consecutive dry periods (CDD) is noted, suggesting a worsening of drought conditions over the years. This calls for attention to water resource management and climate change adaptation strategies in the region.

The problems associated with extreme precipitation events in Goiânia are widely recognized by the population and frequently reported in the media. These include water and food insecurity during droughts, as well as floods, inundations, urban mobility issues, material damage, and loss of lives caused by extreme rainfall events.

In this context, the climate crisis highlights the need for effective climate governance, which involves defining and implementing public policies for climate mitigation and adaptation (focused on better water management, improving urban drainage system, and strengthening flood protection measures). Although there are climate policies at the national and state levels, the municipal level still lacks adequate action plans and contingency measures. The response to these crises often occurs only after extreme events, without adopting fixed and definitive strategies that promote greater resilience for both the territory and society considering the challenges posed by climate change.

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References

ALEIXO, A.; ALBERNAZ, A. L. M. K.; VIVEIROS GRELLE, C. E.; VALE, M. M.; RANGEL, T. F. Mudanças Climáticas e a Biodiversidade dos Biomas Brasileiros: Passado, Presente e Futuro. *Natureza & Conservação*, v. 8, n. 2, p. 194-196, 2010.

ALVES, W. S.; CABRAL, J. B. P.; NASCIMENTO, D. T. F. Influências do El Niño Oscilação Sul (ENOS) e da Oscilação Decenal do Pacífico (ODP) na variabilidade dos totais anuais de chuva em Goiás e no Distrito Federal. *Caminhos de Geografia*, v. 24, p. 321-338, 2023.

ALVES, W. S.; CABRAL, J. B. P.; NASCIMENTO, D. T. F. A participação do El Niño Oscilação Sul (ENOS) e da Oscilação Decenal do Pacífico (ODP) nas chuvas em Goiás e no Distrito Federal. *Revista Ra'e Ga ¿ Espaço Geográfico em Análise*, v. 55, p. 176-200, 2022.

ARTAXO, P. Mudanças climáticas e o Brasil. *Revista USP*, [S. l.], n. 103, p. 8-12, 2014.

ALMEIDA, J. M. V. de. *Índices de monitoramento e detecção de mudanças climáticas na região Centro-Oeste do Brasil*. 2012. 178f. Dissertação (Mestrado em Meteorologia) – Pós-Graduação em Meteorologia, Centro de Tecnologia e Recursos Naturais, Universidade Federal de Campina Grande, Paraíba, Brasil, 2012.

CARDOSO, M. R. D.; MARCUZZO, F. F. N.; BARROS, J. R. Classificação climática de Köppen-Geiger para o estado de Goiás e o Distrito Federal. *Acta Geográfica*, v. 8, p. 40-55, 2014.

CHAVES, J. V. B. *et al*. Rede de Sensores para avaliação de variáveis meteorológicas em áreas verdes urbanas: desenvolvimento e aplicações. *Sociedade & Natureza*, v 34, e64675, 2022.

DEUS, R. M. M.; NASCIMENTO, D. T. F. Eventos climáticos extremos no estado de Goiás e Distrito Federal. In: SIMPÓSIO BRASILEIRO DE CLIMATOLOGIA GEOGRÁFICA, 2021, João Pessoa. Anais do XIV SBCG. João Pessoa: UFPE, 2021. v. 1. p. 2938-2954.

EVANGELISTA, A. W. P.; CORRECHEL, V.; ARANTES, N. R. de M.; ALVES JUNIOR, J.; CASAROLI, D. Padrões hidrológicos e período de retorno das chuvas erosivas em Goiânia-GO. *Gl. Sci Technol*, Rio Verde, v.09, n.02, p.1 – 12, mai/ago. 2016.

HOFMANN, G. S.; CARDOSO, M. F.; ALVES, R. J. V.; WEBER, E. J.; BARBOSA, A. A.; TOLEDO, P. M.; PONTUAL, F. B.; SALLES, L. O.; HASENACK, H.; CORDEIRO, J. L. P.; AQUINO, F. E.; OLIVEIRA, L. F. B. *The brazilian Cerrado is becoming hotter and drier*. Global Change Biology, p. 1-14, 2021.

IPCC. Climate Change 2021*: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.). Cambridge, UK and New York, NY, USA: Cambridge University Press, 2021.

KARL, T. R.; NICHOLLS, N.; GHAZI, A. *CLIVAR/GCOS/WMO workshop on indices and indicators for climate extremes*: Workshop summary. Climatic Change, v. 42, p. 3-7, 1999.

LUIZ, G. C. *Influência da relação solo-atmosfera no comportamento hidromecânico de solos tropicais não saturados*: estudo de caso - município de Goiânia-GO. 2012. 246 f. Tese (Doutorado em Geotecnia) - Universidade de Brasília, Brasília, DF, 2012.

LUIZ, G. C.; ROMÃO, P. de A. Interação Solo-Atmosfera e Processos de Inundação e Alagamento na Cidade de Goiânia-GO. *Revista Brasileira De Geografia Física*, v. 12, p. 1891-1903, 2019.

MARENGO, J. A. et al. *Impactos de extremos relacionados com o tempo e o clima* – Impactos sociais e econômicos. Boletim do Grupo de Pesquisa em Mudanças Climáticas. Instituto Nacional de Pesquisas Espaciais – INPE. Centro de Ciências do Sistema Terrestre - Edição Especial. 2009.

MONTEIRO, C. A. de F. *Teoria e Clima urbano*. São Paulo: IGEOG/USP, 1976. 181 p. (Série Teses e Monografias, 25).

MONTEIRO, C. A. de F. Notas para o estudo do clima do Centro-Oeste brasileiro. *Revista Brasileira de Geografia*. v. 13, n. 1, p. 3-46, jan-mar 1951.

NASCIMENTO, D. T. F. *Chuvas no estado de Goiás e no Distrito Federal a partir de estimativas por satélite e circulação atmosférica.* 2016. 200 f. Tese (Doutorado em Geografia) - Universidade Federal de Goiás, Goiânia, 2016.

NASCIMENTO, D. T. F.; COSTA, Q. S. Permanência do regime de precipitação entre diversos anos-padrão habituais, secos e chuvosos: estudo de caso para Goiânia-GO. *Geoambiente on-line*, p. 1-14, 2020.

NASCIMENTO, D. T. F.; LIMA, L. V.; CRUZ, V. Episódios e gênese dos eventos climáticos extremos em Goiânia-GO. *Caderno de Geografia*, v. 29 n. 57, p. 583-608, 2019.

NASCIMENTO, D. T. F.; NEVES, G. Z. de F. Dinâmica atmosférica na área core do bioma Cerrado. IN: NASCIMENTO, D. T. F.; MARTINS, A. P.; LUIZ, G. C.; LOPES, R. M. *Climatologia do Cerrado*: variabilidades, suscetibilidades e mudanças climáticos no contexto do Cerrado brasileiro. Goiânia: C&A Alfa Comunicação, 2021. Cap. 9, p. 232-262.

NASCIMENTO, D. T. F.; OLIVEIRA, I. J. Os sistemas atmosféricos atuantes e responsáveis pela gênese das chuvas no estado de Goiás e no Distrito Federal. *Revista Brasileira de Climatologia*, v. 27, p. 747-71, 2021.

NEVES, G. Z. F. *Distribuição geográfica das chuvas no Estado de Goiás e Distrito Federal*: dinâmica e aplicações nos estudos rítmicos. 2018. Tese (Doutorado) – Universidade de São Paulo, São Carlos, 2018.

NIMER, E. *Climatologia do Brasil*. Rio de Janeiro: IBGE, 1979.

PEREIRA, P. R. C.; NASCIMENTO, D. T. F.; OLIVEIRA, I. J. de. Emprego do geoprocessamento na delimitação e análise das áreas verticalizadas em Goiânia (GO) e sua relação com o padrão espacial das temperaturas superficiais terrestres. In: XIV SIMPÓSIO BRASILEIRO DE GEOGRAFIA FÍSICA APLICADA, 2011, Dourados. Anais do XIV SBGFA, 2011.

PETERSON, T. C.; FOLLAND, C.; GRUZA, G.; HOGG, W.; MOKSSIT, A.; PLUMMER, N. *Report on the Activities of the Working Group on Climate Change Detection and Related Rapporteurs 1998-2001*. Rep. WCDMP-47, WMO-TD 10712001. Geneve: WMO, 143p.

PETERSON, T. C. Climate Change Indices. *WMO Bulletin*, v. 54, n. 2, p. 83-86, 2005.

RIBEIRO, W. Impactos das mudanças climáticas em cidades no Brasil. *Parcerias Estratégicas*, Brasília, n. 27, p. 297-321, 2008.

REGO, T. L.; BARROS, J. R. Alagamentos e inundações em Goiânia: uma análise a partir da imprensa local e dos registros da defesa civil. *Revista Formação (online)*, v. 1, p. 170-185, 2014.

RODRIGUES, A. A.; MACEDO, M. N.; SILVÉRIO, D. V.; MARACAHIPES, L.; COE, M. T.; BRANDO, P. M.; SHIMBO, J. Z.; RAJÃO, R.; SOARES-FILHO, B.; BUSTAMANTE, M. C. Cerrado deforestation threatens regional climate and water availability for agriculture and ecosystems. *Global Change Biology*, 2022. Doi:

SANTOS, C. A. C. dos; BRITO, J. I. B. de; RAO, T. V. R.; MENEZES, H. E. A. Tendências dos índices de precipitação no Estado do Ceará. *Revista Brasileira de Meteorologia*, v. 24, n. 1, p. 39-47, 2009.

SANTOS, L. O. F.; et al. Trends in Precipitation and Air Temperature Extremes and Their Relationship with Sea Surface Temperature in the Brazilian Midwest. *Atmosphere*, 14, 426, 2023.

SCHRODER, Rudolf. Distribuição e curso anual das precipitações no estado de São Paulo. *Bragantia*, v. 15, n. 18, p. 193-250, 1956.

SILVA, C. B.; CARPENEDO, C. B. Teleconexões no Cerrado brasileiro. IN: NASCIMENTO, D. T. F.; MARTINS, A. P.; LUIZ, G. C.; LOPES, R. M. *Climatologia do Cerrado*: variabilidades, suscetibilidades e mudanças climáticos no contexto do Cerrado brasileiro. Goiânia: C&A Alfa Comunicação, 2021. Cap. 9, p. 232-262.

SILVA, G. C.; NASCIMENTO, D. T. F. Variabilidade e tendência climática em Goiânia-GO: avaliação a partir de índices de extremos climáticos calculados em RClimdex. In: SIMPÓSIO BRASILEIRO DE CLIMATOLOGIA GEOGRÁFICA, 2021, João Pessoa. Anais do XIV SBCG. João Pessoa: UFPE, 2021. v. 1. p. 2922-2937.

SILVA, K. V.; LUIZ, G. C.; OLIVIERA, LUCIANO H. de A. A importância das áreas verdes para minimizar o efeito das ilhas de calor na cidade de Goiânia-GO*:* estudo de caso Parque Areião e o centro da cidade. In: SIMPÓSIO BRASILEIRO DE CLIMATOLOGIA GEOGRÁFICA, 12., 2016, Goiânia: UFG, 2016. p. 841-852.

SOUZA, A. C. M.; NASCIMENTO, D. T. F. Os fenômenos de enchente, inundação e alagamento: uma proposta para o processo de ensinoaprendizagem de Geografia. In: Diego Tarley Ferreira Nascimento; Ricardo Junior de Assis Fernandes Gonçalves. (Org.). *Águas do cerrado*: gestão, usos e conflitos. 1ed.Goiânia: Editora Kelps, 2018, v. 1, p. 177-188.

STREGLIO, C. F. da C.; NASCIMENTO, D. T. F.; OLIVEIRA, I. J. O processo de expansão urbana e seus reflexos na redução da cobertura vegetal no município de Goiânia-GO. *Ra'e ga: o espaço geográfico em análise*, n. 28, p.181-197. 2013.

WILHITE, D. A. Breaking the Hydro-Illogical cycle: progress or status quo for drought management in the United States. *European Water*, n. 34, p. 5-18, 2011.

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