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Climatological Norms and the Effects of Climate Changes on Brazilian Capitals

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A B S T R A C T

Over recent decades, shifts in climatic patterns have been observed across both global and regional scales, marked by changes in temperature regimes and the increased frequency of extreme weather events. These alterations are not uniform; instead, they vary according to the distinct geographical and environmental characteristics of each region. A growing body of evidence highlights the rising trend in global average temperatures, largely attributed to human-induced greenhouse gas emissions, with profound implications across multiple sectors. These changes pose serious risks to public health, food security, economic stability, and biodiversity, underscoring the need for region-specific climate analyses. This study focuses on the climatological norms of Brazilian capitals, examining long-term trends in air temperature to identify any significant shifts. By employing the nonparametric Mann–Kendall trend test at a 5% significance level, we analyze the patterns and tendencies of temperature changes over time. Our findings reveal statistically significant trends in various regions, highlighting areas with pronounced warming and potentially increased vulnerability to climate impacts. This research contributes to a more nuanced understanding of localized climate change effects, emphasizing the necessity for targeted mitigation strategies and adaptation policies. By focusing on the unique climate dynamics of Brazil's capital cities, we aim to support informed decision-making processes, ultimately aiding in the formulation of region-specific responses to minimize the adverse effects of climate change.

Keywords: climate change, climatological norms, Mann-Kendall.

Introduction

The effects and impacts of climate change on natural ecosystems, agriculture, and water resources at global, regional, and local scales are evident worldwide. Various factors contribute to the intensification and increase in climatic variabilities. Recent studies have indicated that the increase in the Earth's surface temperature in recent decades is attributed to anthropogenic actions, particularly greenhouse gas emissions (Neto, 2021; Moreira, 2022; IPCC, 2022).

According to the Intergovernmental Panel on Climate Change, (IPCC, 2022), the climate crisis is rapidly worsening, with impacts much more severe than anticipated. Its effects, affecting everything from food production (Campetella & Robles, 2020), to the formation of heat islands (Mitchell, 2016), have destabilized societies and the environment in a global and unprecedented manner.

Long-term changes in weather conditions have severe impacts on food security, availability, accessibility, and utilization. Similarly, changes in mean temperatures and rainfall will affect the suitability of land for crops, pasture, and productivity of marine resources. It will also increase the incidence of pests and diseases; loss of biodiversity, a decline of ecosystem functioning; reduce the availability of water for crop, livestock, and inland fish production.

Climate change affects food security for communities that depend on rain-fed agriculture. In this regard, climate change is expected to reduce global cereal production by 1–7% in 2060 (IPCC, 2022).

Analyzing the air temperature variability in a specific region is essential for understanding climate change and seeking means to mitigate its consequences. This analysis is crucial for better understanding modifications that have occurred over the years for the prevention of current or future problems.

According to the IPCC report (IPCC, 2022), 2021 was considered the sixth warmest year ever recorded, with the global average between 2012 and 2021 showing an increase of 0.76°C above the 1961-1990 average.

Climatological norms serve two main functions. First, these data can serve as a reference for comparison with recent or current observations, including by providing a basis for many climatic datasets based on anomalies (e.g., global average temperatures). They are also widely used, implicitly or explicitly, to predict the most likely conditions to be experienced in a particular location (World Meteorological Organization [WMO], 2018).

. Climatological norms are periodic averages computed uniformly over a relatively long period, comprising at least three consecutive decades (WMO, 2019).

Air temperature is a crucial indicator for assessing the impact of human activities on the global climate. Monitoring temperature trends allows us to identify patterns and understand the consequences of climate change. Analyzing these variations is essential for developing public policies and adaptation strategies (Parmesan, 2016).

Additionally, the increase in air temperature is directly linked to impacts on human health, biodiversity, water resources, and agricultural production. With rising air temperatures, many regions worldwide face more intense droughts, more frequent and severe heatwaves, and extreme weather events, such as hurricanes and floods (Watts, 2019).

In Brazil, the National Institute of Meteorology (INMET) has consolidated data for the climatological norm for the period from 1961 to 1990. However, the period from 1991 to 2020 is still under evaluation and recording, providing an opportunity for data exploration and updating climatological results.

Temperature extremes, their frequency and intensity, have generated major economic, environmental and social impacts. A study (Barbosa, 2019) analyzed historical trends and future projections using climate models and observational data, confirming a significant increase in the intensity and frequency of extreme weather events in South America, including Brazil. Another study (Geirinhas et al., 2021) observed that states such as São Paulo, Rio de Janeiro and Minas Gerais have recorded pronounced increases in episodes of drought and extreme temperatures.

In this context, understanding air temperature variations in Southern Brazil, considering its regional peculiarities, is fundamental for developing effective mitigation and adaptation strategies to climate change, minimizing its negative effects on society and the environment.

Thus, the objective of this article was to analyze the climatological norms of the capitals of Brazil for the periods from 1961 to 1990 and 1991 to 2020, aiming to identify changes in air temperature.

Materials and methods

Study area

The study was conducted across the 27 capitals of Brazil (Figure 1), representing the five regions of the country: North, Northeast, South, Southeast, and Midwest. Each region has unique climatic characteristics due to Brazil's vast size, geographical diversity, and variety of biomes, ranging from equatorial rainforests in the North to temperate zones in the South.

For this study, temperature data from all Brazilian capitals, including Brasília in the Federal District, were analyzed. This approach allows a comprehensive examination of temperature trends and variations across the entire country, providing insights into both regional and national climatic shifts.

The diverse climate profiles across these regions make Brazil a valuable case for studying temperature patterns and assessing the impacts of climate change on different ecosystems and urban settings.

The specifics of the data collection site, and regional climates are detailed in Table 1.

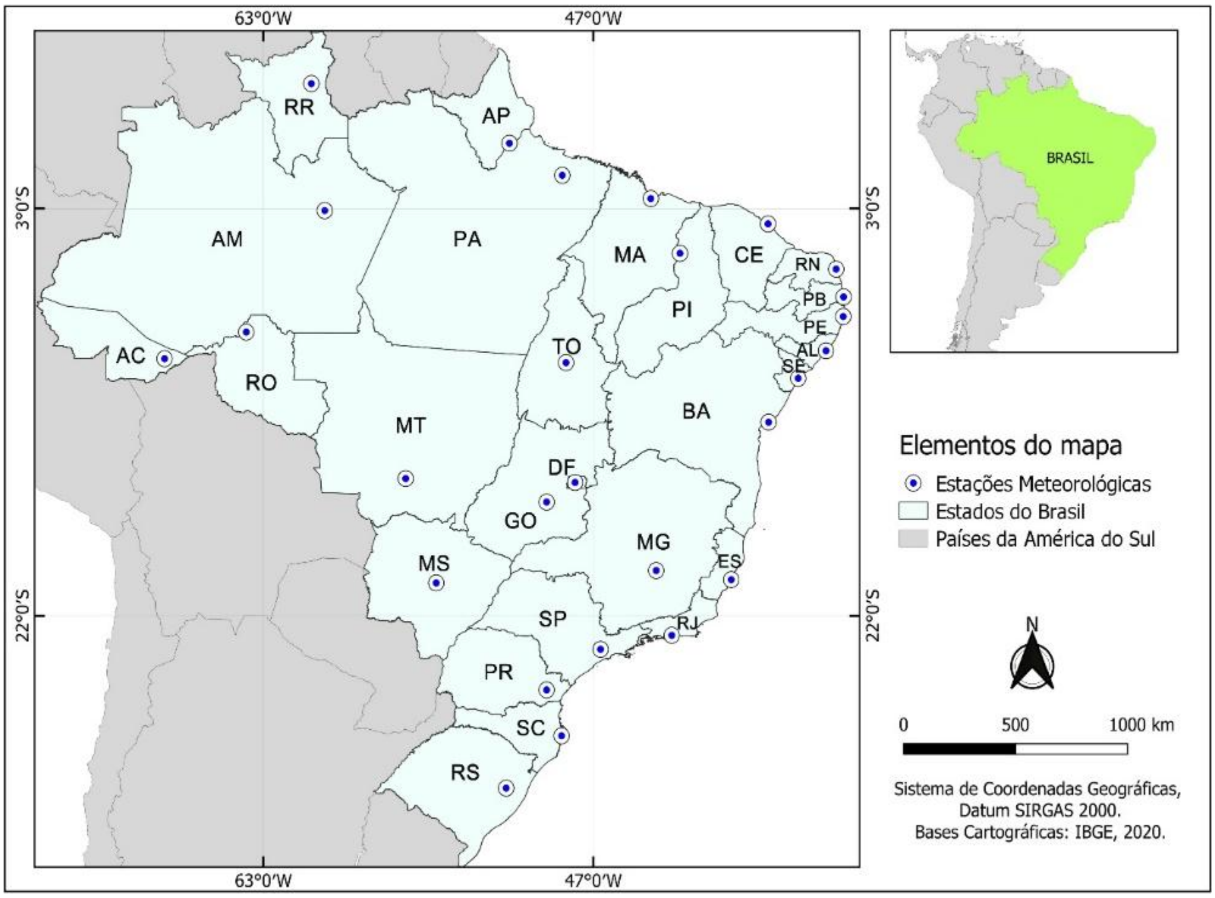

Figure 1. Map of Brazil with 26 states and 1 Federal District.

Table 1 presents the geographical location of the meteorological stations for each of the capitals, along with the identification code and the data period.

Meteorological data

In this analysis, data provided by the monitoring network of the National Institute of Meteorology - Brazil (INMET), a federal agency under the direct administration of the Ministry of Agriculture, Livestock, and Supply (MAPA), were used.

To analyze variations in climatological norms on a broader scale and to detect regional differences, meteorological stations located in Brazilian capitals were selected. Daily air temperature series for the period of 1961–2020 were analyzed and subdivided into two representative data series for climatological norms: 1961–1990 (NCI) and 1991–2020 (NCII). Each series comprises a set of data for a 30-year climatological norm. Climatological norms are recommended by the World Meteorological Organization (WMO) and serve as reference periods for climate comparison criteria to identify changes in climatological patterns (Parmesan, 2016).

Consistency Analyses

For consistency of the air temperature and precipitation data, norms established by the World Meteorological Organization's (INSTITUTO NACIONAL DE METEOROLOGIA DO BRASIL, [INMET], 2022) guide for quality control of climatological data were used in the climatological data program. The following items were considered:

- Identification of missing or repeated data (monthly series with less than 20 days were disregarded, as was annual series with more than 2 months without data);
- Identification of false sequences of the number zero (sequences of three or more consecutive zeros were considered unreal data and eliminated);
- Occurrence of unacceptable extreme values (values that exceed the historical limits of each meteorological variable used).

Table 1. Location and code of the meteorological stations by region.

WEATHER STATIONS						
State	Capital	Latitude	Longitude	Altitude	Code	Period
North						
Acre	Rio Branco	-9.95916	-67.86888	160.7	82915	1961-2020
Amapá	Macapá	-0.04499	-51.11	12.8	82098	1967-2020
Amazonas	Manaus	-3.10333	-60.01638	61.2	82331	1961-2020
Pará	Belém	-1.43583	-48.43722	7.1	82191	1961-2020
Rondônia	*Porto Velho	-8.7931	-63.8467	86.1	82825	1961-2020
Roraima	Boa Vista	2.82944	-60.66194	84.1	82024	1961-2020
Tocantins	**Palmas	-10.19089	-48.30182	291.6	83033	1961-2020
Northeast						
Alagoas	Maceió	-9.55138	-35.77083	84.1	82994	1961-2020
Bahia	Salvador	-13.00583	-38.50583	47.3	83229	1961-2020
Ceará	Fortaleza	-3.81527	-38.53777	29.8	82397	1961-2020
Maranhão	São Luiz	-2.52666	-44.21361	32.5	82280	1961-2020
Paraíba	João Pessoa	-7.09527	-34.84861	9.6	82798	1961-2020
Pernambuco	Recife	-8.05916	-34.95916	11.3	82900	1961-2020
Piauí	Teresina	-5.03472	-42.80138	75.7	82578	1961-2020
Rio Grande Do Norte	Natal	-5.83722	-35.20777	47.6	82598	1961-2020
Sergipe	Aracajú	-10.9525	-37.05444	3.6	83096	1961-2020
Midwest						
Distrito Federal	Brasília	-15.78972	-47.92583	1161.4	83377	1961-2020
Goiás	Goiânia	-16.67305	-49.26388	748.5	83423	1961-2020
Mato Grosso	Cuiabá	-15.61999	-56.10888	157.7	83361	1961-2020
Mato Grosso Do Sul	*Campo Grande	-20.44725	-54.72264	528.4	83611	1961-2020
Southeast						
Espírito Santo	Vitória	-20.31583	-40.31694	36.2	83648	1961-2020
Minas Gerais	Belo Horizonte	-19.93444	-43.95222	915.47	83587	1961-2020
Rio De Janeiro	*Rio de Janeiro	-22.89555	-43.18472	37.5	83743	1961-2020
São Paulo	São Paulo	-23.49638	-46.61999	785.16	83781	1961-2020
South						
Paraná	Curitiba	-25.44861	-49.23055	923.5	83842	1961-2020
Santa Catarina	Florianópolis	-27.6025	-48.62027	4.64	83897	1961-2020
Rio Grande Do Sul	Porto Alegre	-30.05361	-51.17472	41.18	83967	1961-2020

*For the meteorological station of Porto Velho, data from the conventional station cover the period from 1961 to 2008 and were complemented with data from the automatic station (code A925).
*Meteorological station of Campo Grande. Data from the conventional station cover the period from 1961 to 2009 and were complemented with data from the automatic station (code A702).
*Meteorological station of Rio de Janeiro; data from the conventional station cover the period from 1961 to 2017 and were complemented with data from the automatic station (code A621). **Due to insufficient data, data from the Porto Nacional station (code 83064), located 60 km away at latitude -10.71083333, longitude -48.40638888, and altitude 243.08 m were used.

Statistical analyses

After being checked for consistency, air temperature data (maximum, average and minimum) and precipitation data were subjected to analyses on a temporal scale: monthly, seasonal, and annual.

The studied periods were statistically analyzed using the nonparametric Mann–Kendall test at the 5% significance level. When the p value < 0.05, the null hypothesis is rejected in favor of the alternative hypothesis, indicating a trend in the series. A positive tau value indicates a positive trend in the series, whereas a negative tau value indicates a negative trend. The data were analyzed using R Studio software.

With the increasing importance of monitoring climate variabilities and changes and their impacts on the economy, the environment, health, and natural disasters, updating climatological norm calculations over the years has become essential for identifying possible changes in variable patterns (Gavrilov, 2016).

A study carried out in the city of Santa Catarina, southern Brazil (Ávila, 2022) confirmed the occurrence of climate change based on the analysis of air temperature and precipitation trends. In recent decades, especially from 2000 onward, the growing vulnerability to the effects of terrestrial climate has raised constant concerns about the state of global climate change, whether due to natural variability or human activity interference.

Results and discussion

The results obtained for the dataset of analyzed climatological norms (NCI and NCII) can be observed in Table 2 for each studied variable according to the capital through trend analysis using the Mann–Kendall test at the 5% significance level. For each variable, the sign indicates an increasing trend when positive (+) or a decreasing trend when negative (-) over the years. When the test is not significant, i.e., p value > 0.05, then there is no trend (ns) over the years.

Table 2. Comparative trend analysis of variable changes using the Mann–Kendall test with data from Climatological Norms 1 and 2 (NCI and NCII).

Capital	Maximum air temperature		Average air temperature		Minimum air temperature	
	NCI	NCII	NCI	NCII	NCI	NCII
Rio Branco	+	ns	+	+	-	ns
Macapá	+	+	+	+	+	+
Manaus	-	+	ns	+	+	+
Belém	-	+	+	+	+	+
Porto Velho	-	+	-	+	+	+
Boa Vista	ns	+	+	+	+	+
Palmas	ns	+	+	+	+	+
Maceió	+	+	-	+	-	+
Salvador	+	+	+	-	+	-
Fortaleza	+	+	+	+	+	+
São Luiz	+	+	+	+	+	+
João Pessoa	+	+	+	+	+	-
Recife	+	+	+	+	+	-
Teresina	+	+	-	+	-	+
Natal	+	+	+	+	ns	+
Aracajú	+	+	+	+	+	+
Brasília	-	+	+	+	+	+
Goiânia	+	+	+	+	+	+
Cuiabá	-	+	-	+	+	-
Campo Grande	+	+	+	+	+	+
Vitória	-	+	+	+	+	+
Belo Horizonte	+	+	+	+	+	+
Rio de Janeiro	ns	ns	ns	-	ns	ns
São Paulo	+	+	+	+	+	+
Curitiba	ns	+	+	+	+	+

Florianópolis	+	+	+	+	-	+
Porto Alegre	-	+	-	+	-	+

It is possible to observe a trend toward a temperature increase at the national level for different measurement forms, i.e., maximum, average and minimum. The maximum temperature showed a positive trend for most capitals concerning NCII, where only Rio Branco and Rio de Janeiro did not show a trend.

Approximately 92% of the analyzed capitals demonstrated an increasing trend for the last climatological norm, with the capitals of Cuiabá, Teresina, Porto Alegre, and Porto Velho showing a trend reversal from negative to positive concerning the analyzed norms.

Among these capitals, Cuiabá experienced significant population growth, leading to increased urbanization. This growth, approximately 90% compared to that in the 1960s, according to IBGE data, may be associated with the observed temperature increase phenomenon, as also noted in a study carried out in the state of Mato Grosso (Silva & Tarifa, 2017). The replacement of natural surfaces such as forests and grasslands, along with the increased concentration of pollutants in the atmosphere from industries and vehicles, has a significant impact on the local microclimate. The combination of these factors results in a gradual increase in the analyzed variable, as observed in the mentioned cities.

The capitals that showed a negative trend for the average air temperature based on the NCII were Salvador and Rio de Janeiro, representing approximately 7.7% of the capitals in Brazil. Despite this trend, the values found for the average temperature in the NCII were still higher than those in the first norm but very close, indicating that there were no extreme climate changes between the analyzed years.

For the minimum temperature, the capital species that showed a decreasing trend in the NCII were Salvador, João Pessoa, Recife, and Cuiabá. Salvador exhibited lower minimum temperatures in the winter months than did NCI, a phenomenon also observed in a study in the state of Minas Gerais (Ávila, 2014) where cities such as Caldas, Poços de Caldas, and São Lourenço showed a negative trend in June; however, unlike Salvador, these cities are directly influenced by factors such as altitude.

For the cities of João Pessoa, Recife, and Cuiabá, the monthly minimum temperatures in the NCII are still above those in the NCI but very close, especially in the winter months for the first two countries.

The Table 2 indicates a clear trend of rising temperatures across most Brazilian capitals, influenced by urbanization and climate change. While some cities show signs of temperature stabilization or slight decreases, the overall pattern aligns with global climate trends, emphasizing the need for continued monitoring and adaptation strategies to mitigate the effects of climate change on urban environment.

Table 3 shows the differences in the maximum, average and minimum air temperatures between the climatological norms, referred to as the NCII (1991-2022) and NCII (1961-1990). All the Brazilian states follow the global trend line, indicating a reduction in minimum temperature and an increase in maximum temperature when represented by their capitals, except for the state of Alagoas, where the Maceió station showed a negative amplitude for minimum temperature (a reduction of 0.26°C in the NCII), and the state of Bahia, represented by the Salvador meteorological station, which had a reduction of 0.08°C.

From the analysis of the variation in average temperature between climatological norms, approximately 19% of the capitals resulted in an increase of more than 1°C. Among the capitals, São Paulo and Rio de Janeiro stand out as the most populous cities in the country, both showing significant variations of 1.16°C and 1.34°C, respectively. Despite Rio de Janeiro not showing a trend toward increase, as shown in Table 2, the temperature remains at higher levels than that of other capitals due to natural geographical conditions and, primarily, due to urban growth observed over the decades, as well as São Paulo.

Figure 2 represents the difference between the analyzed climatological norms (NCII-NCI) concerning the average air temperature. The analysis of temperature fluctuations in Brazil's capitals highlights significant trends in average air temperature, particularly in states with strong agricultural sectors.

The states that experienced the most notable positive fluctuations in average air temperature were Rio de Janeiro, where the temperature increased by 1.34°C; Goiás, with an increase of 1.27°C, particularly in the capital, Goiânia; Tocantins, with a rise of 1.18°C, prominently observed in Palmas; and São Paulo, with an increase of 1.16°C. These changes are indicative of broader climatic trends that have been affecting various regions differently, reflecting the growing impact of both natural and anthropogenic factors on temperature patterns.

Table 3. Differences between the Maximum, Average, and Minimum Temperature Values of Capitals in Brazil between Climatological Norms II and I.

REGION	STATE	WEATHER STATION	MAX.T (°C)	AVE.T (°C)	MIN.T (°C)
NORTH	AC	Rio Branco	0,24	0,58	1,57
	AP	Macapá	1,18	0,81	0,68
	AM	Manaus	0,79	0,75	0,76
	PA	Belém	0,73	0,95	1,01
	RR	Boa Vista	1,43	0,82	1,05
	TO	Palmas	1,24	1,18	1,43
NORTHEAST	AL	Maceió	0,91	0,14	-0,26
	BA	Salvador	0,70	0,28	-0,08
	CE	Fortaleza	0,97	0,50	0,32
	MA	São Luís	1,14	0,70	0,79
	PB	João Pessoa	0,88	0,82	1,20
	PE	Recife	3,84	0,55	0,51
	PI	Teresina	0,48	0,37	0,33
	RN	Natal	0,38	0,50	0,48
	SE	Aracaju	1,01	0,41	0,01
MIDWEST	GO	Brasília*	0,41	0,81	0,95
	GO	Goiânia	1,44	1,27	0,90
	MT	Cuiabá	0,63	0,76	0,65
	MS	Campo Grande	0,92	0,87	1,13
SOUTHEAST	ES	Vitória	0,49	0,71	0,74
	MG	Belo Horizonte	0,16	0,88	1,43
	RJ	Rio de Janeiro	2,84	1,34	0,61
	SP	São Paulo	1,19	1,16	0,95
SOUTH	PR	Curitiba	0,70	1,02	1,26
	SC	Florianópolis	1,21	0,77	0,17
	RS	Porto Alegre	0,79	0,41	0,34

*Federal District Brasilia - Capital of Brazil.

In the states of Tocantins and Goiás, the agricultural sector plays a crucial role in their economies, and its practices have a profound influence on the environment (Fragoso & Cardoso, 2002). Agricultural activities, especially those related to livestock and crop production, are significant contributors to greenhouse gas emissions. Methane, carbon dioxide, and nitrous oxide are among the primary pollutants released during these processes. Methane is particularly associated with livestock digestion and manure management, while nitrous oxide arises from the use of nitrogen-based fertilizers.

Furthermore, the presence of exposed and degraded soils, which is often a result of intensive livestock farming and deforestation, exacerbates environmental challenges. Such conditions contribute to an increase in surface temperatures due to reduced vegetation cover, which otherwise helps to regulate local climates. Soil degradation also accelerates the mineralization of carbon reservoirs, a process triggered by erosion and the breakdown of organic matter. This, in turn, leads to the release of substantial amounts of carbon dioxide (CO_2) into the atmosphere, intensifying the greenhouse effect and further elevating temperatures. These dynamics highlight the interconnectedness of agricultural practices and climate change, emphasizing the need for sustainable land management and mitigation strategies to reduce environmental impacts.

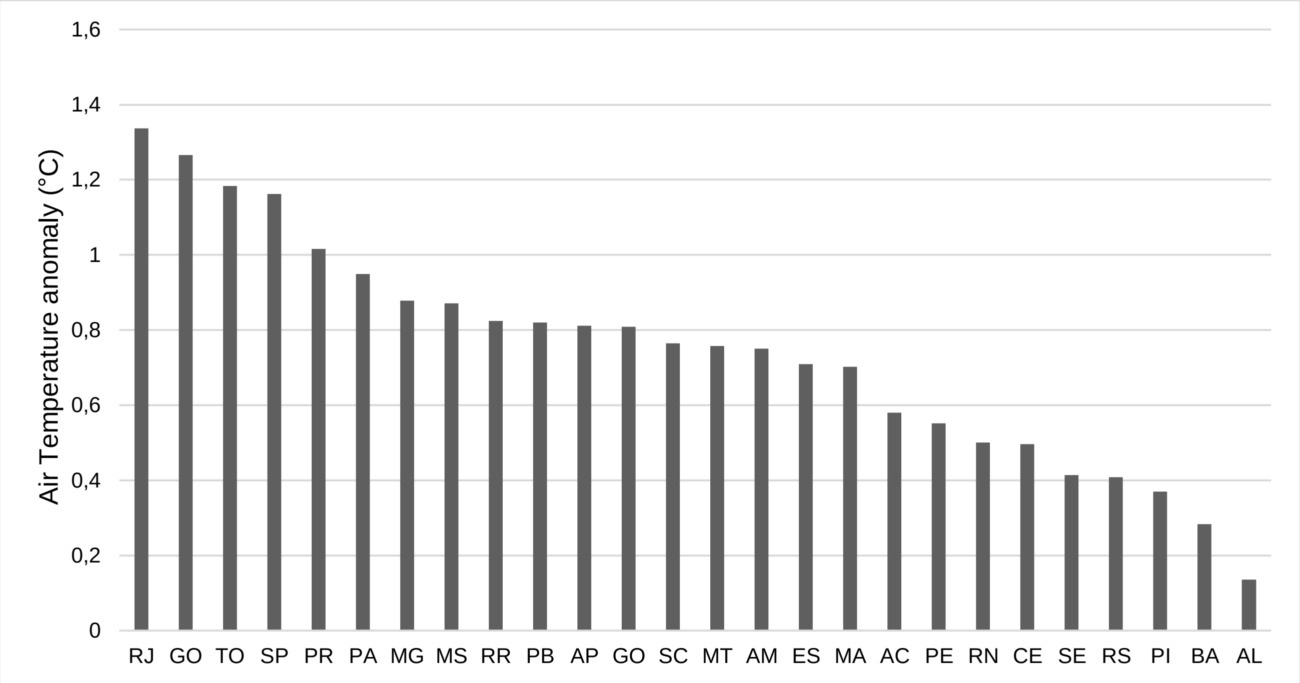

Figure 2. Difference in descending order of average air temperature between the two analyzed climatological norms (NCII-NCI) in the capitals of Brazil.

The increasing average air temperatures in Brazilian states, particularly those with significant agricultural activity, highlight an urgent need for the adoption of sustainable practices. Agricultural sectors in these regions not only contribute to greenhouse gas emissions but also face amplified risks due to climate change, such as reduced crop yields, soil degradation, and increased vulnerability to extreme weather events.

Addressing these challenges requires an integrated approach. Reducing greenhouse gas emissions from agriculture, such as methane from livestock and nitrous oxide from fertilizers, is critical. This can be achieved through methods like improved manure management, rotational grazing, and the adoption of precision agriculture to optimize fertilizer use. Simultaneously, promoting soil health through conservation agriculture, agroforestry, and the recovery of degraded pastures is essential to enhance carbon sequestration and improve ecosystem resilience.

Moreover, the interplay between agriculture and climate change emphasizes the need for coordinated policies that balance environmental sustainability with economic viability. Investments in research, education, and technology transfer are pivotal to equip farmers with tools and knowledge for adapting to changing climatic conditions. By prioritizing these strategies, Brazil can lead efforts to mitigate climate change while ensuring long-term food security and agricultural productivity.

The graph in Figure 3 illustrates the monthly difference in average air temperature between the climatological norms of the three capitals that showed the most significant positive amplitudes. For the Rio de Janeiro meteorological station, the greatest variations occurred during spring and summer, with the difference reaching 2.06°C in October, followed by December (1.78°C), January (1.73°C), and February (1.72°C). During autumn and winter, the city showed reduced differences, with the months of August (0.84°C), July (0.81°C), and May (0.70°C) having the smallest differences.

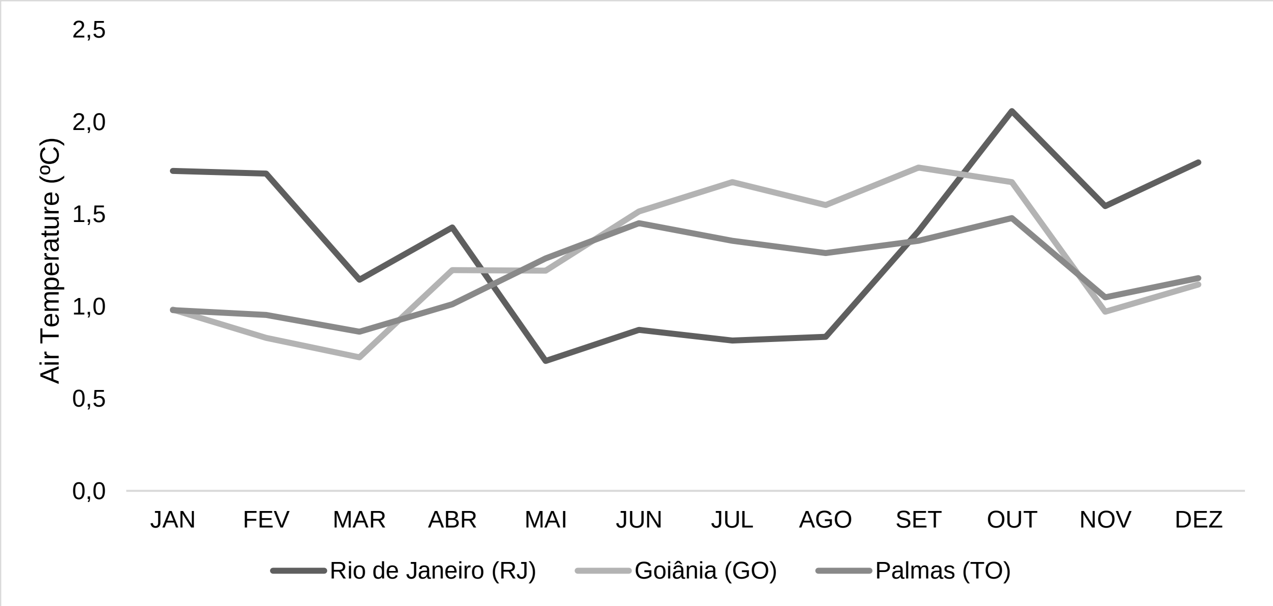

Figure 3. Differences in observed average temperature between NCIIs and NCIs in the cities of Rio de Janeiro, Goiânia, and Palmas.

Goiânia and Palmas showed a contrary behavior to Rio de Janeiro, where the smallest variations were observed during the spring and summer months. For Goiânia, the highest variation occurred in September, with a difference of 1.75°C, followed by July and October, both of which had values of 1.67°C. The months with the smallest differences were November (0.97°C), followed by February (0.83°C), and finally, March, with a difference of 0.72°C. For Palmas, the highest variation occurred in October, with a difference of 1.48°C, followed by June (1.45°C) and July (1.36°C), while the smallest variations occurred in January (0.98°C), February (0.95°C), and March (0.86°C).

The Figure 3 indicates a clear trend of rising temperatures in Rio de Janeiro, particularly during the warmer months of the year. This trend shows the importance of monitoring climate patterns to inform public health measures, urban planning, and environmental policies aimed at mitigating the impacts of climate change on urban populations and ecosystems.

The observed increases in average air temperature, especially during warmer months, can have several implications, as higher temperature can lead to increased hear stress for population and may affect local agriculture, altering growing seasons and crop yields.

Figure 4 shows the relationships between the increase in average temperature and population growth over time for the capitals of different regions of the country. The regions that showed the greatest increase in average temperature when comparing NCIs with NCIIs were the regions that experienced the greatest population growth, except for the Southeast.

This region, represented by its capitals, exhibited a less significant increase than did the others because, in the 1960s, it already had very high population indices, which were even greater than those of most regions in 2020, when represented by their respective capitals. This is mainly because the Southeast, which includes three major metropolises (São Paulo, Rio de Janeiro, and Belo Horizonte), experienced the greatest variation in average temperature, which is closely related to microscale climate changes such as the formation of heat islands due to the replacement of natural surfaces.

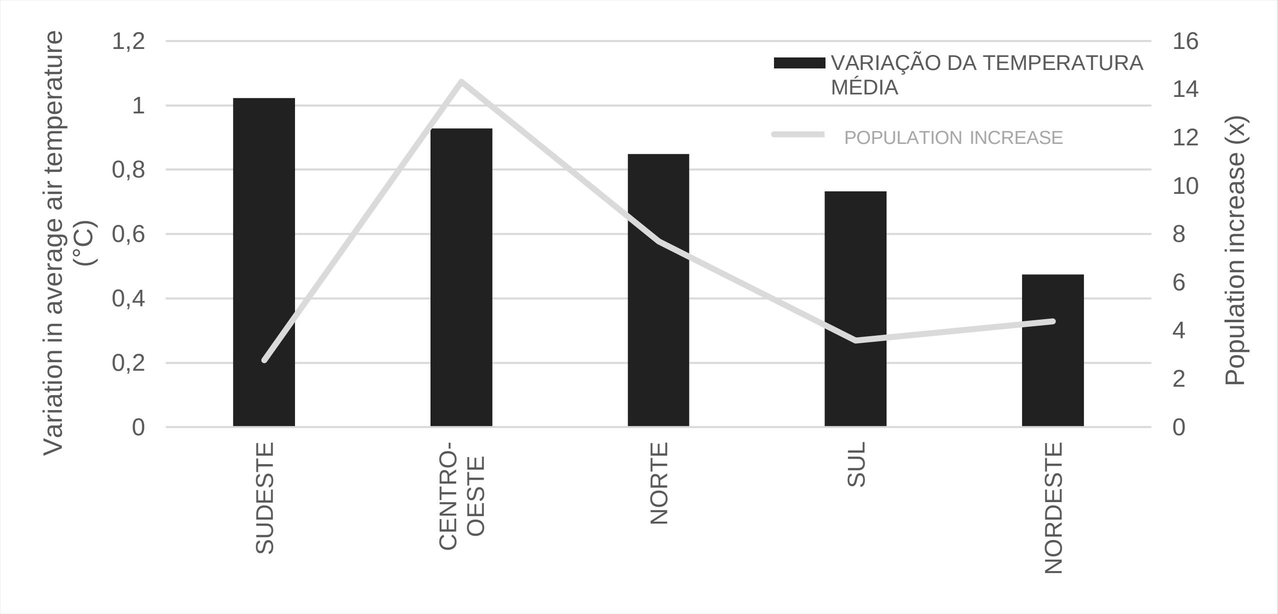

Figure 4. Relationships between the increase in average temperature and population growth over time for the capitals of different regions of the country.

Regions with significant population growth generally exhibited greater increases in average temperatures when comparing climatological norms (NCIs) to later norms (NCIIs). For the year 2020, the populations of the Midwest and North regions increased by 14.31 and 7.96 times, respectively, compared to the populations in the 1960s. This population increase directly impacts the climate of the region, as a larger population leads to greater demand and strain on various infrastructures, such as transportation and housing. Due to the strong influence of these factors, the observed average temperature in the Midwest increased by approximately 0.9°C, while that in the North region increased by approximately 0.84°C.

Despite having a relatively larger population increase than the southern region, the northeast region had a smaller increase in average temperature. This occurs because the economic activities in both regions have different natures, with one being more related to agricultural activities and the other having a more developed and concentrated industrial sector, which consequently causes climatic impacts on a larger scale, especially due to the release of atmospheric pollutants in large quantities.

Conclusion

The global average temperature is increasing, primary due to greenhouse gas emissions from human activities. This trend has been links to various adverse effects on public health, food security, and biodiversity.

Some climate changes are irreversible; however, mitigating these changes is possible by controlling anthropogenic actions and reducing environmental impacts, such as greenhouse gas emissions from the burning of fossil fuels, deforestation, and wildfires. These human-driven factors continue to intensify climate instability and degrade ecosystems, posing an urgent call for more stringent environmental regulations and sustainable practices.

Although scientists have highlighted the pressing need for action, these recommendations have largely been ignored in current government action plans. On the contrary, deforestation, wildfires, and soil degradation—particularly from agricultural expansion and urban development—have increased significantly in recent years. This process raises major concerns, as there are indications we are approaching a critical threshold, or a “point of no return,” where climate and environmental changes may become irreversible, leading to substantial loss of biodiversity and the destabilization of global and regional climates.

Given these findings, it is evident that increasing research at local and regional levels is essential. This expanded research base will not only improve the precision of climate impact predictions but also strengthen mitigation strategies that are tailored to the unique conditions of each area. The more localized data we collect, the better-informed policymakers will be in creating targeted solutions that enhance resilience in vulnerable communities.

This calls for a collaborative approach where government, scientific, and community stakeholders work closely to implement adaptive practices, foster sustainable land management, and prioritize ecosystem conservation.

Only through comprehensive, multi-scale research and informed decision-making can effective adaptation strategies be developed, guiding a sustainable path forward and addressing the complexities of climate change on both regional and global scales. Analyzing positive and negative trends is crucial for minimizing climate change and its potential impacts.

Data Availability Section

Data is provided within the supplementary information files.

Acknowledgments

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References

Ávila, L. F; Mello, C. R; Yanagi, S. N. M; Neto, O. B. S (2014). Trends in minimum and maximum air temperatures in the State of Minas Gerais. Pesquisa Agropecuaria Brasileira, v. 49, n. 4, p. 247–256.

Ávila, A. C. M; et al. (2022) Climate change and its effect on the soil water balance of Lages, Santa Catarina. Revista Brasileira de Geografia Física v.15.

Barbosa, H. M. J.; et al. (2019) Heatwaves in Brazil: historical trends and future projections. Climatic Change, 152(1-2), 103-116.

Campetella.; Robles (2020). Deaths from heatwaves increased by 50% in just 20 years: The increasingly intense heatwaves are one of the deadliest faces of the climate crisis. In this report, we tell how our way of life is in danger if we do not act responsibly. Meteored. Brasília, p. 1-3. Dec 16.

Fragoso, D. B.; Cardoso, E. A. (2002) Agriculture and Climate Change in the State of Tocantins: Vulnerability, Projections, and Development. p. 51–65.

Gavrilov, M. B. et al. (2016). Analysis of annual and seasonal temperature trends using the Mann–Kendall test in Vojvodina, Serbia. Quarterly Journal Of The Hungarian Meteorological Service, v. 120, n. 2, p. 183-198.

Geirinhas, J. L.; Russo, A.; Libonati, R.; Sousa, P. M.; Miralles, D. G.; Trigo, R. M. (2021). Recent increasing frequency of compound summer drought and heatwaves in Southeast Brazil. Environmental Research Letters, Volume 16, Number 3. DOI: 10.1088/1748-9326/abe0eb.

IPCC – Intergovernmental Panel on Climate Change, 2022.

Instituto Nacional De Meteorologia Do Brasil – INMET. Brasília - DF, 2022.

Mitchell, D. (2016). Attributing human mortality during extreme heatwaves to anthropogenic climate change. Environmental Research Letters, v. 11.

Moreira, A. T. R.; et al. (2022) The impact of anthropogenic action on the environment: global warming. Revista Educação em Foco.

Neto, B. S. (2021) Limitation of greenhouse gas emissions, deforestation, and economic growth in Brazil: a prospective analysis. Revista Colóquio do Desenvolvimento Regional da Faccat. v. 18, n. 4.

Parmesan, C. (2016) Influences of species, latitudes and methodologies on estimates of phenological response to global warming. Global Change Biology, vol. 13, no. 9, p. 1860-1872.

Silva, M. P.; Tarifa, J. R (2017). Rhythm Of Temperature In The Local Climate Of The City Of Cuiabá-Várzea Grande (MT): A secular analysis (1912 to 2012). Biodiversity, v. 16, n. 2, p. 2–20.

Watts, N.; (2019) The 2018 report of the Lancet Countdown on health and climate change: shaping the health of nations for centuries to come. The Lancet, vol. 392, no. 10163, pp. 2479-2514.

World Meteorological Organization. WMO (2018) n° 100: Guide to Climatological Practices. Secretariat of the World Meteorological Organization, Geneva.

World Meteorological Organization. WMO (2019) n° 49: Technical Regulations: General Meteorological Standards and Recommended Practices. Vol. 1, Secretariat of the World Meteorological Organization, Geneva.