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Research paper

Rainfall analysis in Xingu River Basin based on the 1981-2020 timeframe

Análise pluviométrica na Bacia Hidrográfica do Rio Xingu com base no período de 1981 a 2020

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ABSTRACT: It is essential understanding the incidence of hydrometeorological variables in each river basin to help planning actions focused on guaranteeing multiple water uses, environmental preservation and prevention measures taken against extreme events. The aim of the current study is to investigate rainfall trends in Xingu River Hydrographic Basin (XRHB) from 1981 to 2020. Data propensity analysis was carried out based on the Mann-Kendall methods, on five-year moving average graph, as well as on variations in Climatological Normals (CN) recorded from 1981 to 2010 and from 1991 to 2020. Moreover, the Log-Normal theoretical distribution was adjusted to show mean rainfall predictions within 10-to-100-year return time (Rt). It was done by applying the Kolmogorov-Smirnov (KS), Chi-Square (χ^2), Filliben (Fi) and Anderson-Darling (AD) tests. Results have evidenced historical series with no trend and minimal variation (-0.5%) between the two CN intervals. Estimates within a 10-to-100-year RT scenario have evidenced rainfall rates higher than the historical average (HA) ranging from 10.0% to 20.0%. Thus, XRHB is a promising scenario for water security planning purposes, since it meets the fundamentals of Brazilian environmental and water resources laws, as well as target 6.5 of Sustainable Development Goal 6 (SDG 6 - UN), which deals with implementing integrated water-resources management at global level.

Keywords: Water security, Amazon Basin, Climate change, SDG 6-UN, Amazon.

RESUMO: O conhecimento acerca da ocorrência das variáveis hidrometeorológicas em uma bacia hidrográfica é fundamental para o planejamento visando garantir o uso múltiplo das águas, preservação ambiental e prevenção contra eventos extremos. De forma a contribuir com tal premissa, este trabalho apresenta o estudo de tendência das chuvas na Bacia Hidrográfica do Rio Xingu (BHRX), no período de 1981 a 2020, no qual foram realizados a análise de propensão dos dados pelos métodos de Mann-Kendall e do gráfico da média móvel de cinco anos, além da variação das Normais Climatológicas (NC) dos períodos de 1981/2010 e 1991/2020. Adicionalmente, visando revelar prognósticos de precipitações médias com 10 a 100 anos de tempo de retorno (Tr), fez-se o ajuste da distribuição teórica Log-Normal, que foi avalizada pelos testes de aderência de Kolmogorov-Smirnov (KS), Qui-Quadrado (χ^2), Filliben (Fi) e Anderson-Darling (AD). Os resultados mostram séries históricas sem tendência e variação ínfima entre os dois intervalos de NC, que se estabelece no patamar de -0,5%. Em um cenário para Tr entre 10 e 100 anos, as estimativas revelam precipitações superiores à média histórica (MH) na ordem de 10,0% a 20,0%. Desta forma, observa-se um cenário promissor, na BHRX, ao planejamento da segurança hídrica, algo que vem ao encontro dos fundamentos das leis ambientais e de recursos hídricos brasileiras, assim como da meta 6.5 do Objetivo de Desenvolvimento Sustentável 6 (ODS 6-ONU), que trata da implementação da gestão integrada dos recursos hídricos em nível mundial.

Palavras-chave: Segurança hídrica, Bacia Amazônica, Mudanças climáticas, ODS 6-ONU, Amazônia.

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INTRODUCTION

The Amazonian region plays key role in Earth’s carbon and hydrological cycles. Global temperature increase will gradually change the rainfall regime on all continents, and it will enable extreme flood and drought events to take place more often (Silva *et al.*, 2021; INMET, 2023). Thus, a dichotomous Amazonian region is expected in the future, with sectors showing high rainfall rates, whereas others will lack rainfall events for long periods-of-time. Therefore, it is necessary conducting studies focused on predicting likely climate features in the future, to guide actions aimed at mitigating climate impacts on both society and regional production chains.

Accordingly, water management (WM) plays key role in preventing such a scenario from taking place in Brazil. Therefore, it is essential understanding the manifestations of hydro-meteorological events in river basins to help planning water–resources use, with emphasis on establishing water security (a GH tool), in its broadest sense, to guarantee multiple water uses, environmental preservation and prevention measures taken against extreme events, which are essential items for Brazil's sustainable development (IPEA, 2022; ANA, 2023a).

Thus, analyzing the atmospheric part of the hydrological cycle, i.e., rainfall, is of paramount importance for GH, since rainfall accounts for watercourses’ flow magnitude, as well as for renewing groundwater stocks. Rainfall events are currently monitored by the National Hydrometeorological Network (RHN), which accounts for approximately 80% of the rain gauge stations operating in Brazil. The National Water Agency (ANA) and the Geological Survey of Brazil (SGB-CPRM) account for RHN’s management, operation and maintenance processes based on technical cooperation (ANA, 2017).

In normative and legal terms, Federal Law n. 9433/1997 provides on water management in Brazil. It also addresses the concept of National Water Resources Information System (SNIRH), which accounts for storing, organizing and spreading data collected by RHN, which, in their turn, should be acknowledged as support to guide environmental preservation actions and Brazilian socio-economic development (Brasil, 1997; ANA, 2023b).

Considering the foregoing, there is clear need of assessing the potential of rainfall events to renew the stored stocks of both surface and groundwater. It must be done to enable the multiple use of this resource, as well as to estimate the incidence of extreme rainfall events to socio-economically defend the population in favor of an integrated water/society/environment management process (Santos *et al.*, 2023).

Similar concept was presented by Penner *et al.* (2023), who highlighted the relevance of understanding groundwater stocks for water management purposes, since this topic remains poorly investigated in the literature associated with tropical zones, such as the Amazonian region. This scarcity of studies forces researchers to use indirect methods to estimate water volumes and hydrogeological parameters.

According to Darwich, Aprile and Siqueira (2024), who analyzed rainfall events’ distribution in the Brazilian Amazon, hydrological years in this region do not follow a single period. They are distributed between April/March and October/September in North-South direction, as well as between December/November and October/September in East-West direction. Based on this information, which was gathered by analyzing total rainfall rates in seven capital cities in Northern Brazil, it is hard to investigate rainfall trends in the Amazon region b taking into consideration the hydrological year in the Amazonian region.

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This finding is corroborated by the Operation Report of the Hydrological Alert System for Xingu River (watercourse belonging to the Amazonian Hydrographic Region), which is formulated on a yearly basis to inform society about the flooding dynamics in this river and about its consequences for the environmental components of its hydrographic basin. This system is an important tool used to plan water security strategies, since more than 190,000 people were vulnerable to flooding events in BHRX, after Belo Monte Hydroelectric Power Plant (HPP) started operating. The aforementioned document shows differences between rainy periods in the upper, middle and lower Xingu stretches; the most intense rainfall events happen in the basin's South-North direction, on a yearly basis (Oliveira; Matos, 2023).

Given the circumstances described above, namely: vulnerable population, the operation of a hydroelectric plant that generates clean energy for the country and the fact that it is part of the Amazonian Hydrographic Region (RH Amazônica), which experienced severe drought in the 2023/2024 biennium (INPE; INMET, 2023), it is possible stating that BHRX is a strategic target for studies on water resources. It is so, because, based on Brazilian regulations, knowledge resulting from these studies should support GH to help balancing the water/society/environment relationship and enabling Brazilian development under sustainable conditions (Brasil, 1997; Santos *et al.*, 2023).

Accordingly, the current study provides an analytical overview of the incidence, magnitude and frequency of rainfall events in BHRX between 1981 and 2020, as well as presents mean rainfall forecasts in return periods up to 100 years to establish likely scenarios for this region. The current findings are expected to support the implementation of integrated management systems in the study site, which, as previously mentioned, hosts a hydroelectric power plant (Belo Monte) that plays key role in the country's socio-economic development. However, this project's implementation has fostered socio-environmental degradation in its host municipality (Altamira) as explained by Xavier and Pereira Júnior (2021), who also associated this fact with the precarious urban infrastructure observed in the affected areas.

In addition, Sevá Filho (2005) outlined likely scenarios of impacts by the herein assessed hydroelectric dam on BHRX in the medium- and long-terms. According to these scenarios, changes in Xingu River dynamics can have consequences for traditional communities living in this river basin, as well as for the flow of water deriving from its main tributaries.

MATERIALS AND METHODS

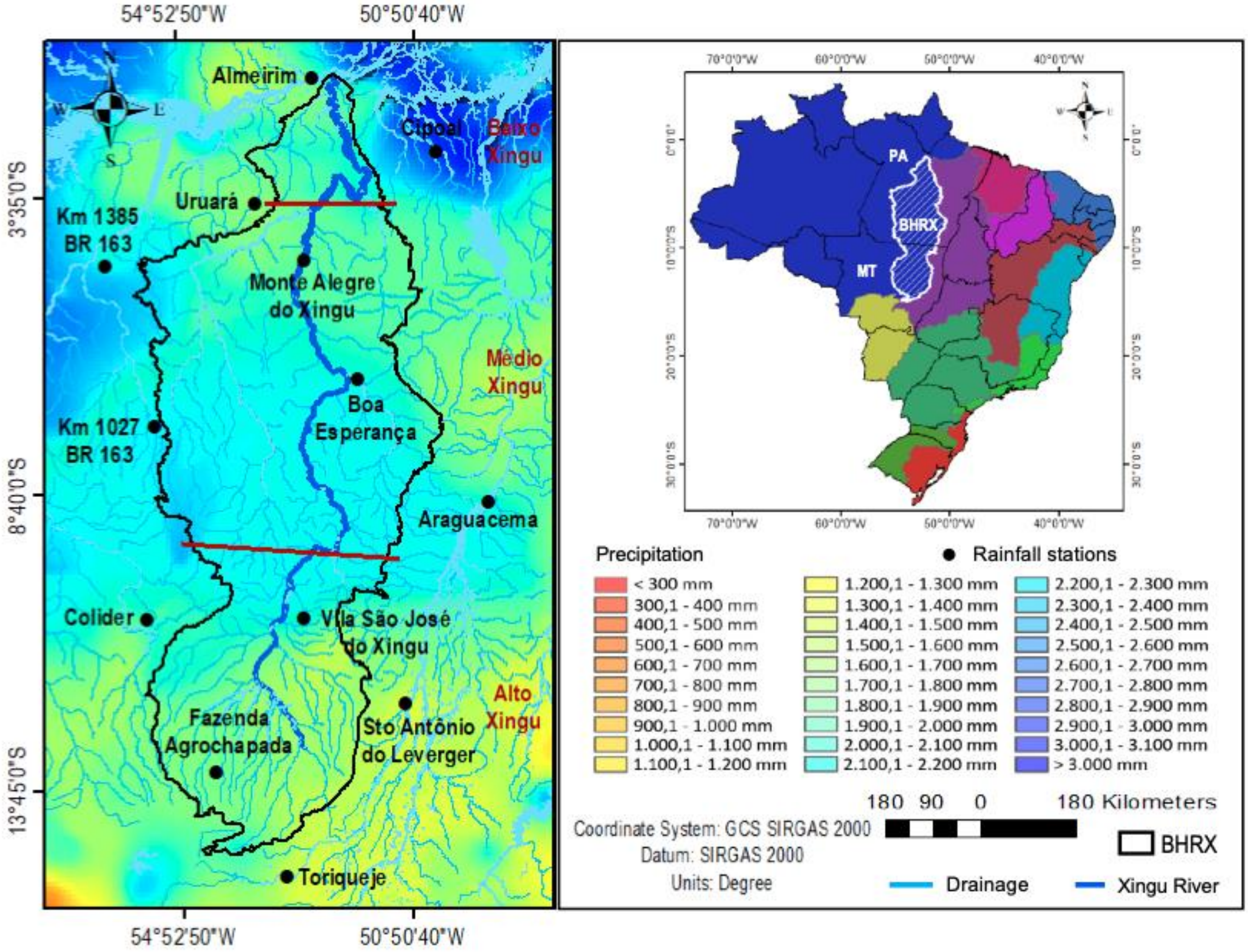
Study site

Xingu River Basin (BHRX) is part of the Amazon River Basin, besides being simultaneously divided between Pará and Mato Grosso states.

It covers approximately 509,000 km^2 and is bordered by Araguaia/Tocantins RH to the East, as well as by Paraguay RH to the South. Xingu River has mean long-term flow (QMLT) of 8,548 m^3/s and 95% permanence flow (Q95) of 1,184 m^3/s (Lucas, 2022).

According to the Isohyetal Map of the Brazilian Rainfall Atlas (Pinto *et al.*, 2011), the mean annual rainfall rate in far South the investigated area ranges from 1,400mm to 2,000mm, whereas that at the mouth of the main river ranges from 1,800mm to 2,200mm. However, the central section of BHRX is the one recording the most significant rainfall rates, which range from 2,400mm to 2,600mm, as shown in Figure 1This figure also introduces the rainfall stations used in the current study (ANA, 2023b).

Figure 1. Annual rainfall indices and BHRX location.



Source: Prepared by the authors, with data from Pinto *et al.* (2011) and ANA (2023b).

The study site is influenced by the South Atlantic Convergence Zone (SACZ) during the dry season (from May to October), as well as by the Intertropical Convergence Zone (ITCZ) during the rainy season (from November to April) (Cunha, 2021). However, other meteorological systems, such as instability lines, as well as convective and frontal systems, act in this region over the year. This weather variability tends to produce extreme rainfall events in case of atmospheric imbalance, and it potentiates floods and droughts, whose magnitude is directly proportional to the socio-economic and environmental damage to the affected areas (Franco *et al.*, 2018; Back; Galatto; Souza, 2024).

According to Cunha (2021), BHRX lies in the transition zone between the Amazonian (92.3%) and Cerrado (7.7%) biomes - 60% of its surface is covered by protected areas. It is important emphasizing that comparative studies about deforested and forested environments in the Amazonian region have shown that replacing forests with pastures decreased annual evapotranspiration rates in the investigated region by approximately 30%, rainfall rates by 25% and runoff rates by 20% (Araújo; Ponte, 2016).

As previously mentioned, the analyzed basin hosts a hydroelectric power plant that represents a step forward in the quest to update the energy sector to meet social demands and those of Brazilian productive sectors. However, deforestation applied to establish pastures and to increase grain production - which, according to hydroclimatic studies, can change the hydrological cycle in the investigated region and lead to high temperatures and extreme drought events -, puts this project at risk of getting inoperable at monthly intervals, given the downward trend of Xingu River minimum flow, which is extremely precarious (Oliveira *et al.*, 2020; Lipski *et al.*, 2023).

BHRX is located at altitude of 847m, near the source of the main river (Mato Grosso), and at approximately 86m at its mouth, where it meets the Amazon River (Pará), after covering a distance of 2,000km (Cunha, 2021). This physiographic feature helps Xingu River to achieve higher flows than those of other rivers involved in hydroelectric power projects. Among them, one finds São Francisco and Paraná Rivers, which account for 50% and 85% of Xingu River's flow at peak flood, at Paulo Afonso and Itaipu HPPs, respectively (Nattrodt; Dias, 2021).

With respect to the subsurface configuration, Figure 2 shows that the investigated area comprises crystalline environments, mostly in middle Xingu River, as well as sedimentary environments, to the North and South of the basin (left) (SGB-CPRM, 2004). In addition, layers with high potential to produce water are limited to the Northern and Southern extremes of the study site (right) (SGB-CPRM, 2014).

According to the Groundwater Information System (SIAGAS), the use of subsoil water resources in BHRX is virtually distributed all over its area, although the middle section of it is mainly formed by crystalline rocks. This system holds approximately 300 wells with stabilized flow rate ranging from $1m^3/h$ to $45m^3/h$ in Pará State, and 250 wells with stabilized flow rate ranging from $0.5m^3/h$ to $110m^3/h$ in Mato Grosso State. These wells are distributed in sedimentary formations, mainly in Alter-do-Chão, Curuá, Ererê and Monte Alegre municipalities, in the North, as well as in Ronuro and alluvial deposits, in the South. Wells in the crystalline domain mainly draw water from Xingu, Creporizão and Rio Maria units (Schobbenhaus *et al.*, 2004; SG-CPRM, 2024).

Given the current climate change scenario, it is essential understanding the potential use of groundwater to favor water security. According to Olivos e Méllo Jr. (2023), hydrological studies conducted in river basins should always favor the integration of, and reciprocal effects between, surface and groundwater.

Moreover, with respect to the link between forest suppression and changes in rainfall regime, data collected by Lucas (2022) have evidenced that deforestation in BHRX has been mostly extensive in its Eastern and Southern regions over the last two decades, when forest reduction rates over the basin reached 16.4%, on average. Thus, one can conclude that the renewal of underground stocks is also at downward trend in this region, since the smaller number of forests leads to decreased rainfall rates and, consequently, to drop in water infiltration in the soil (Araújo; Ponte, 2016).

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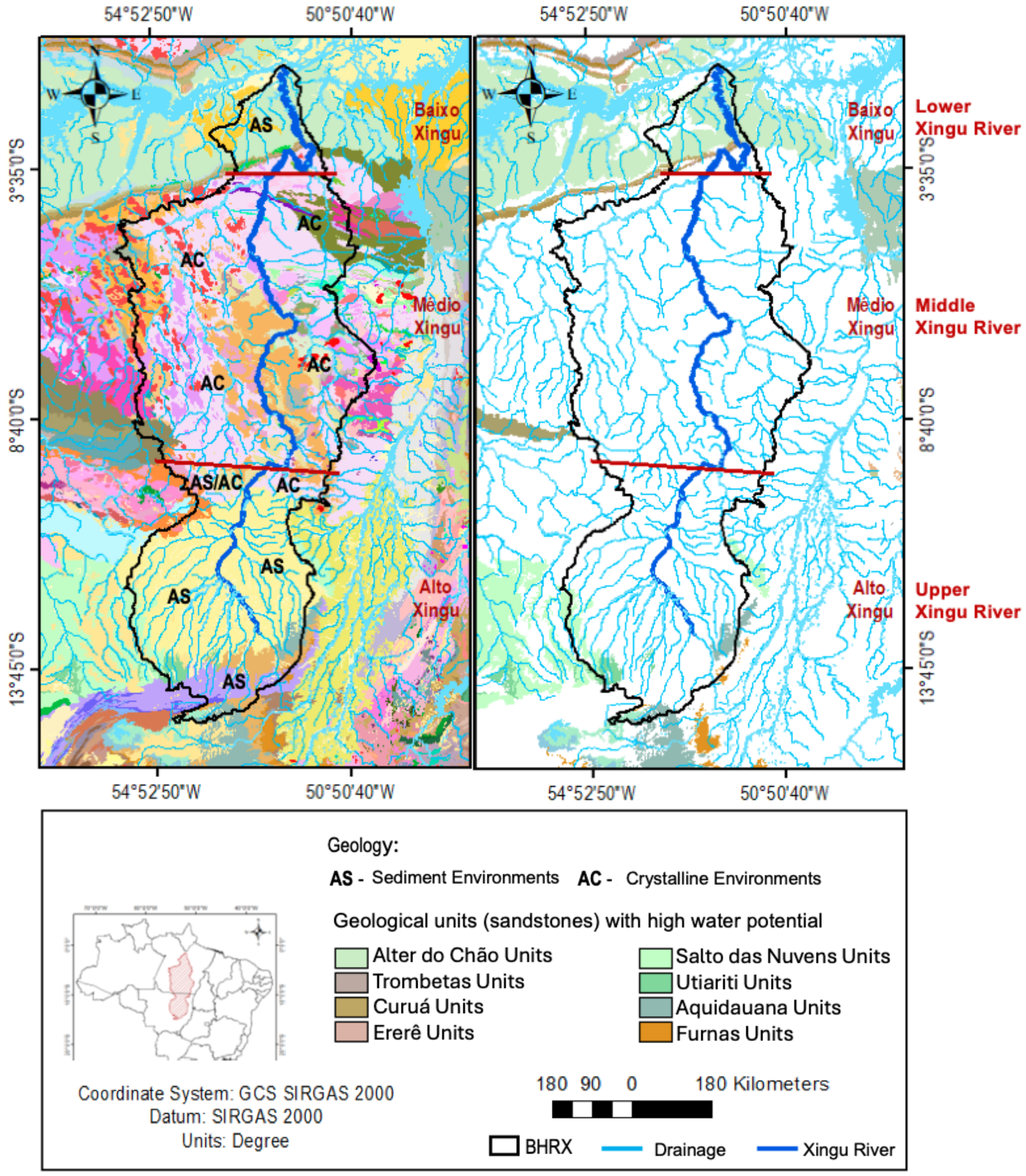
Figure 2. BHRX Geology and Hydrogeological Potential.



Source: Prepared by the authors, with data from Schobbenhaus *et al.* (2004) and SGB-CPRM (2014).

Data collection and analysis

The historical series provided by rainfall stations shown in Figure 1 were collected at the National Water Agency's Hidroweb (ANA, 2023b): Almeirim (00152005), Cipoal (00250000), Uruará (00353000), Monte Alegre do Xingu (00452000), KM 1385 BR 163 (00455003), Boa Esperança (00651001), KM 1027 BR-163 (00655001), Araguacema (00849002), Vila São José do Xingu (01052000), Colíder (01055002), Santo Antônio Leverger (01250001), Fazenda Agrochapada (01354000) and Toriqueje (01552002). This information was used to calculate the mean monthly and annual rainfall rates in the investigated basin based on the Arithmetic, Thiessen and Isohyetal methods, which were systematized through the equations below. Further information on these methods can be found in Marciano *et al.* (2018) and Barbosa Júnior (2022).

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Revista Brasileira de Ciência, Tecnologia e Inovação
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- Arithmetic method:

$$P_m = \frac{1}{N}\sum_{i=1}^{N} P_i \qquad (1)$$

Wherein:
Pm is the mean rainfall rate in the basin (mm);
Pi is the rainfall rate at the support station (mm);
N is the number of used supports.

- Thiessen method:

$$P_m = \frac{\sum A_i \, . \, P_i}{A} \qquad (2)$$

Wherein:
Pm is the mean rainfall rate in the basin (mm);
Pi is the rainfall rate at the station (mm);
Ai is the area of influence of the station (km2);
A is the total area of the basin (km2).

-Isohyetal method:

$$P_m = \frac{1}{A}\sum \left[\frac{1}{2}\left(P_i + P_{i+1}\right) A_{i,i+1}\right] \qquad (3)$$

Wherein:
Pm is the mean rainfall rate in the basin (mm);
Pi is the rainfall rate corresponding to the isohyet of order i (mm);
Pi+1 is the rainfall rate corresponding to the isohyet of order i+1 (mm);
Ai, i+1 is the area between the isohyets of orders i and i+1 (km^2);
A is the total area of the basin (km^2).

Some series presented gaps that were filled in at monthly and annual level based on using the regional weighting method:

$$Prec\ A = \frac{Med\ Prec\ A}{3}\left[\frac{Prec\ B}{Med\ Prec\ B} + \frac{Prec\ C}{Med\ Prec\ C} + \frac{Prec\ D}{Med\ Prec\ D}\right] \qquad (4)$$

Wherein, *Prec* A is the gap to be corrected and 3 corresponds to the number of stations used in the correction process (supports).

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Once the complete series was available, mean monthly and annual rainfall rates for 30 consecutive years (1981 to 2010 - 1991 to 2020) were estimated. According to the National Institute of Meteorology (INMET) and to the World Meteorological Organization (WMO), it is possible assuming that the statistical parameters calculated for this period represented the prevalent value of that climate element in the investigated location, based on INMET (2022) and WMO (2017, 2019).

A comparison between the two periods of Climatological Normals was carried out based on the estimated means in order to predict the rainfall variation rate in BHRX, in compliance with INMET guidelines used in climate studies to analyze the incidence of extreme winds.

Then, the 5-year moving average was applied based on using EXCEL spreadsheet tools. It was done by taking into consideration annual historical averages in compliance with procedures adopted by Silva *et al.* (2021). In addition, the non-parametric Mann-Kendall test , which is recommended by the World Meteorological Organization to assess the effects of climate change on rainfall series, was carried out (Medeiros, 2018; Teixeira *et al.*, 2020). The aim of these measures was to visually and statistically identify likely climate change effects on rainfall series.

According to Silva (2017), Medeiros (2018) and Cabral Júnior and Lucena (2020), the Mann-Kendall statistical test is explained as follows:

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i=1} \text{sinal} \ (X_j - X_i) \qquad (5)$$

The signal function (Xj-Xi) is defined by Equation 6. If the series (n) is too large, the S statistic converges to normal distribution, where the average is equal to zero and variance is estimated through Equation 7.

$$\text{Sinal} = \begin{cases} +1 \text{ se } (X_j - X_i) > 0 \\ 0 \quad \text{se } (X_j - X_i) = 0 \\ -1 \text{ se } (X_j - X_i) < 0 \end{cases} \qquad (6)$$

Mean: E[S] = 0

$$\text{Var}\,[S] = \frac{1}{18}\left[n(n-1)(2n+5) \ - \sum_{p=1}^{q} t_p(t_p-1)(2t_p+5) \right] \qquad (7)$$

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Wherein, *n* is the number of data points in the analyzed series and t_p is the number of data points with equal values in each group p. The q component is the number of clusters with equal values in the data series of a given group p.

According to Silva (2017), Medeiros (2018) and Cabral Júnior and Lucena (2020), the parameterized statistical test (Zmk) is defined as follows:

$$Zmk = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & \text{se } S>0 \\ 0, & \text{se } S=0 \\ \frac{S+1}{\sqrt{Var(S)}}, & \text{se } S<0 \end{cases} \quad (8)$$

If |Zmk|>1.96 and Zmk<0, it indicates downward trend. If |Zmk|>1.96 and Zmk>0, it indicates upward trend. Finally, if |Zmk|<1.96, data show no trend (Medeiros, 2018; Xavier Júnior *et al.*, 2020).

To estimate the magnitude of rainfall events in BHRX over up to 100 years, the theoretical distribution best fitting the analyzed data series was selected among Normal, Log-Normal and Gumbel distribution functions, which are those that most closely explain the stochastic behavior of observed rainfall data (Silva, 2020; Dias; Penner, 2021; José *et al.*, 2022). According to Guimarães (2011), a large part of the probabilistic information deriving from the sample can be summarized by the selected theoretical distribution and its respective parameters, after adjustments. The conceptual basis of the distributions described above was described, in details, by Naghettini and Pinto (2007) and Guimarães (2011).

The Kolmogorov-Smirnov (KS), Chi-Square (χ^2), Filliben (Fi) and Anderson-Darling (AD) adherence tests, which were described by Naghettini and Pinto (2007), Guimarães (2011) and Abreu *et al.* (2018), were used to select the best probabilistic modeling. The standard error of estimates set between the observed data and the calculated quantiles was used to validate the indicated theoretical distribution model to further support the tests' results (Naghettini; Pinto, 2007).

RESULTS AND DISCUSSIONS

Table 1 shows the mean annual rainfall rate observed for the herein analyzed timeframe. It is worth emphasizing that just over 7.0% of the set of months taken into consideration in the current study, were filled with totals estimated through the regional weighting method (Equation 4). The mean annual values were calculated based on the Thiessen method, which was consistent with the Arithmetic method. Both methods were slightly dispersed in comparison to the Isohyetal method (±4.0%).

Although rainfall distribution in BHRX has already been explained, according to Marcuzzo *et al.* (2017), it can be approached by taking into consideration the territory of Pará and Mato Grosso states. Thus, according to the maps presented by the aforementioned researchers, the highest mean yearly rainfall distribution rates can be seen in BHRX's central section, which comprises Southern Pará, whereas the lowest values of it are expected to be observed in Southern BRHX, i.e. in Central-Eastern Mato Grosso State. Mean totals are estimated at 2,500mm and 1,700mm, respectively. Accordingly, Back, Galatto and Souza (2024) have emphasized that rainfall events in the study site are seasonal. This condition influences rainfall extremes and favors studies focused on investigating climate change and its impacts on the environment. Moreover, according to Marcuzzo *et al.* (2017) and Cunha (2021), the wettest period of the year extends from November to April, whereas the driest one encompasses the remaining months – this information is corroborated by the Rainfall Atlas of Brazil (Pinto *et al.*, 2011).

Table 1. Mean annual rainfall rate in BHRX between 1981 and 2020.

Year	$R_{\text{mean annual}}$ (mm)	Year	$R_{\text{mean annual}}$ (mm)	Year	$R_{\text{mean annual}}$ (mm)	Year	$R_{\text{mean annual}}$ (mm)
1981	1677,2	1991	1822,0	2001	1877,8	2011	1791,1
1982	1936,7	1992	1875,7	2002	1841,0	2012	1701,4
1983	1569,0	1993	1871,3	2003	1827,9	2013	1874,2
1984	1918,7	1994	2173,6	2004	2040,6	2014	2100,6
1985	2311,1	1995	1906,5	2005	1977,0	2015	1632,0
1986	1965,1	1996	1823,7	2006	2079,8	2016	1794,3
1987	1649,1	1997	1762,4	2007	1621,2	2017	1994,9
1988	2064,8	1998	1744,3	2008	1863,2	2018	2046,9
1989	2041,9	1999	1790,6	2009	1795,3	2019	1951,9
1990	1799,1	2000	2021,1	2010	1801,1	2020	1744,2

Source: Prepared by the authors.

The magnitude and incidence of rainfall events play key role in estimates of Climatological Normals. Therefore, it is necessary monitoring variations in these parameters to identify changes in meteorological patterns (INMET, 2022).

A comparison between the two periods of Climatological Normals (1981/2010 and 1991/2020) has evidenced that the observed averages fluctuated by approximately -0.5%.

In total, 45% of the 40 analyzed years were affected by the *El Niño* phenomenon, whereas 27.5% of them were affected by the *La Niña* phenomenon. The year recording the lowest rainfall rate - 1983 (1,569.0 mm) - experienced high *El Niño* incidence. However, there is no guarantee that this rainfall rate was only influenced by this climatic event. The year recording the highest total rainfall rate -, 1985 (2,311.1 mm) did not experience any episode of the aforementioned phenomena (CPTEC/INPE, 2021). Nevertheless, it was considered an atypical point, based on sample quartiles and on the interquartile range method described by Naghettini and Pinto (2007), although it was taken into account in the analysis because data related to it were assumed as real.

The herein described analysis followed the approach by Souza *et al.* (2022), who investigated rainfall events in Southern Amazonas mesoregion. Their findings have evidenced positive and negative oscillations at the time to compare successive Climatological Normals in municipalities, such as Apuí, Boca do Acre, Humaitá and Labrea, when the *El Niño* phenomenon was active in the region.

According to Souza *et al.* (2022) and INMET (2022), it is important understanding these fluctuations to substantiate actions aimed at maintaining and/or protecting public health, the economy and social well-being. It is so, because lack or excess of water in the environment tends to trigger events that have straight impact on the quality of life of populations living in urban centers and in the countryside.

Accordingly, Pereira and Nascimento (2020) have emphasized that oscillations seen in successive Climatological Normals, mainly in those associated with variables like

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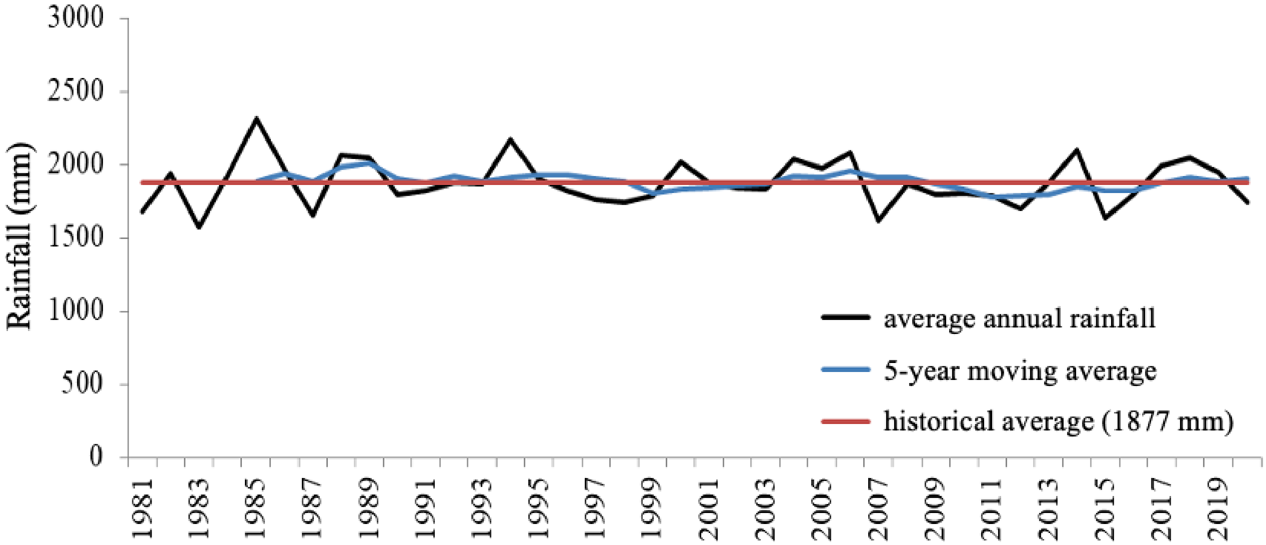
temperature, rainfall and evaporation, can help better understanding changes in the dynamics of water sources that mainly account for supplying urban centers. Such a fact that can lead to public supply vulnerability and to increased social inequalities.

Peres, Aquino and Viana (2023), who investigated rainfall anomalies in South America, concluded that comparing climatological normals provides preventative information. According to them, if changes in rainfall cycles and in the incidence of extreme events are confirmed, contingency and response plans should be developed to help protecting the local and regional economy and infrastructure, mainly when the analyzed area generates wealth through agriculture, livestock and hydroelectric power generation, like the BHRX case.

With respect to trends observed in the historical series shown in Table 1, both the graph of the 5-year moving average and the Mann-Kendall test pointed out a dataset with no trend. Zmk = -0.38, so |Zmk|<1.96 (Equation 8).

Therefore, this series has no trend, and it was corroborated by the moving average shown in Figure 3.

Figure 3. The 5-year moving average set for data shown in Table 1.



Source: Prepared by the authors.

Parameters estimated for all three theoretical distributions proposed in the statistical modeling enabled concluding that Normal and Log-Normal are the most suitable distributions to model the rainfall averages shown in Table 1. Table 2 shows adherence tests' results. Gumbel was rejected by the AD test.

Although the application of the two approved probabilistic models is seen as preferable, the Log-Normal distribution was herein selected to model the rainfall series, given its lower standard error of estimates. However, when deviations of the Normal and Log-Normal distributions in the historical average were compared to each other, small difference was observed between them: 1.1% and 0.97%, respectively.

Figure 4 shows the estimates of HM incidence rates, by return time, in BHRX, for up to 100 years.

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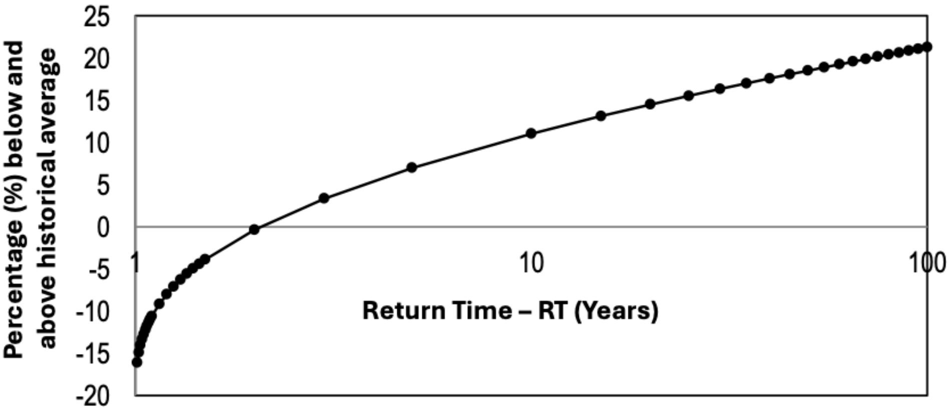
Table 2. Adherence tests' results.

Test	**Test significance level**	**(1) Critical value of the Test statistic**	**(2) Calculation of the Test statistic**			**Model acceptance condition**	**Result of the modeling analysis**		
			Gumbel	**Normal**	**Log-Normal**		**Gumbel**	**Normal**	**Log-Normal**
KS	5%	0,2100	0,16827	0,01570	0,01570	(2)<(1)	accepted	accepted	accepted
χ^2	5%	5,9900	4,09794	2,23220	2,23220	(2)<(1)	accepted	accepted	accepted
Fi	5%	0,9526	1,00000	0,99416	0,99416	(2)<(1)	accepted	accepted	accepted
AD	5%	0,7570	1,447650	0,04498	0,04498	(2)<(1)	not accepted	accepted	accepted

Note: Kolmogorov-Smirnov (KS) / Chi-Square (χ^2) / Filliben (Fi) / Anderson-Darling (AD).

Figure 4. HM incidence rates by return time.



Based on Figure 4, the statistical modeling predicted annual totals higher than the historical average, from +10.0% to +20.0%, over a return time horizon of 10-100 years.

On the other hand, the return time estimated for HM was 2 years, and it can be seen as indicative of rainfall regularity in the study site, a fact that reinforces the Mann-Kendall test results and the arrangement of curves in Figure 3. This last statement is supported by INMET (2022), which reported differences in Climatological Normals between 1961 and 2020 of, at most, 2.5% HM. In addition, Ribeiro *et al.* (2022) carried out a geostatistical analysis of the hydrometeorological variables in the study site and observed constant averages and no trend.

CONCLUSION

The almost imperceptible drop observed by comparing the consecutive periods of Climatological Normals (1981/2010 and 1991/2020) has shown that the study site has little impact on the amount of water renewing stocks. This factor helped maintaining drainage discharges and guaranteeing the preservation of the basin's natural ecosystems. In addition, it is quite promising when water security planning is approached together in the socio-economic context to enable multiple water use, environmental preservation and hydroelectric power generation at Belo Monte power plant. In addition, the lack of trend observed in the historical series corroborates this statement and shows that there has been increase in hydroelectric power generation.

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In addition, the estimated occurrence of historical average with 2-year return time (Tr) has further evidenced normality in surface and groundwater stock renewal. This factor may have positive effect on water supply estimates, since it is subject to little fluctuation and enables implementing more sustainable water-use strategies.

It is worth emphasizing that the herein conducted calculations also pointed out minimal climate change impact on the investigated region, likely because 60% of it is protected by the principles of Law n. 9985/2000, which provides on the creation, implementation and management of nature conservation units in Brazil. In addition, the current findings are following target 6.5 of Sustainable Development Goal 6 (UN SDG 6), which addresses the implementation of integrated water resources management at all governmental levels, in association with civil society and with non-governmental institutions.

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