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Impacts and variability on the urban climate of Recife – Pernambuco, Brazil

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Abstract

The objective of this work was to identify monthly and annual oscillations and trends in meteorological variables: maximum and minimum air temperatures, precipitation, and relative humidity, number of rainy days, total sunshine, wind intensity and cloud cover. We used the theoretical probability distribution: Weibull, Log-normal and Logistics to adjust the values of the variables mentioned above. The Kolmogorov-Smirnov test was used to verify the adjustment of the theoretical functions. The study of the spatial temporal behavior of rainfall and monthly, maximum and minimum temperatures, relative humidity, insolation, cloud cover and wind used was acquired from the National Institute of Meteorology, the data period comprising the series from 1962 to 2015. For The determination of the theoretical distributions of probability adjusted to the annual extremes of precipitation, maximum and minimum temperature of the air, total isolation and relative humidity, cloud cover and wind intensity, were used the maximum likelihood methods to estimate the parameters of the distributions. The Kolmogorov-Smirnov test was used to compare the fit and select the best theoretical distributions. The adjustments were also evaluated in graphs. Deforestation of native vegetation for the construction of districts, favelas and buildings above six floors, as well as high burnings, has contributed to the high rates of desertification, silting up rivers, streams, streams, wells, ponds, ponds and lagoons. Water table, causing extreme fluctuations in the contribution of meteorological elements and well-being in urban centers. The Weibull and Logistics distributions were the best fit for precipitation, insolation, relative humidity, minimum temperature and cloud coverage.

Keywords: Meteorological elements; Climatic oscillations; Probability distribution; Adverse phenomena.

1. Introduction

Climatologically, the Northeast region of Brazil (NEB) is considered semi-arid because it shows temporal and spatial variations in irregular inter-municipal rainfall, as well as high temperatures throughout the year [3]. According to [16], the climate variability of the NEB is influenced by the El Niño phenomenon, associated with major drought events in the region, which causes damage to the populations of these areas.

Environmental comfort is one of the climatic factors that affect people's quality of life. One of the major concerns of the scientific community in the last decade concerns climate change and the consequences for humanity Warming in cities is an intra and interurban fact that has been occurring since the dawn of civilization, as a result of the lack of urban planning, involving aggressions to the natural environment. Urban heating is integrated into the city, even if they are small urban agglomerations, as vertical civil constructions, new neighborhoods, large-scale asphalt coverage, the absence of afforestation and soil compaction have generated a heat island proportional to urban growth.

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In areas with a region with a contrasting climate between rainy and semi-arid, such as the Northeast of Brazil (NEB) and in particular the state of Pernambuco, thermal monitoring is of fundamental interest for decision-making that bring benefits to the inhabitants. Information on historical climatic conditions is important for the planning and management of agricultural crops, for the analysis of the intensity of thermal variability, and the interference of air temperature can be avoided as much as possible, highlighting the conduct of studies concerning agricultural ordination: land use, ecological zoning, climatic suitability, sowing time, crop cycle estimation and population well-being, among others in accordance with [18].

According to [21], climate oscillations are due to the imperceptible balance between the intensity of incident solar radiation and the greenhouse effect, provided mainly by the amount of CO_2 in the atmosphere.

[16] used the Weibull, Log-normal and Logistic probability distribution functions to adjust the values of meteorological variables: maximum and minimum air temperatures, rainfall, relative humidity, and number of days with rain, total insolation, wind intensity and cloud cover in the municipality of Parnaguá - PI. These authors use the Kolmogorov-Smirnov (KS) test to verify the fit of the theoretical functions. For the four theoretical probability distributions adjusted to the annual extremes of the referenced data, maximum likelihood methods were used, in order to estimate the referred parameters.

[14] showed that urban, rural and environmental planning are important, as is the storage of water for multiple purposes. They identified the monthly and annual fluctuations and trends of the meteorological variables: maximum and minimum air temperatures, precipitation, relative air humidity, number of days with rain and total insolation in the municipality of Bom Jesus - Piauí. The Weibull, Log-normal and Logistic probability distribution functions were used to adjust the values of the aforementioned variables. The Kolmogorov-Smirnov (KS) test was used to verify the fit of the theoretical functions. The results revealed an increase in the maximum temperature and a reduction in the minimum temperature, an important condition for the desertification process in the studied area. This variation causes water stress in agricultural crops and, consequently, low production.

[11] calculated the average daily air temperature using different methodologies for the municipalities of Parnaíba, Picos and Gilbués located, respectively, in the coastal area, in the central region of the State of Piauí and belonging to the semi-arid region, in lands of the cerrado and desertified. Four methods were used to calculate the average daily air temperature, the standard recommended by the National Institute of Meteorology – INMET. The four methods evaluated in relation to the standard had a performance classified as "very good and excellent", with a confidence index ranging from 0.83 to 0.98. The results also indicated that, in the climatic conditions of the study region, the four methods evaluated in relation to the standard [6] can be used to estimate the average daily air temperatures.

The constant changes in the climate are causing an increase in the occurrence of extreme weather events worldwide. In Brazil, these events occur mainly as floods (heavy rains) and prolonged droughts, according to [9], In the Northeast of Brazil (NEB), the impacts are even greater, due to the great variability in the occurrence of precipitation in this region. The main systems responsible for the occurrence of precipitation in the NEB are Intertropical Convergence Zone (CZIT), High Level Cyclonic Vortices (HCV), Line of Instability (LI), South Atlantic Convergence Zone (SACZ), Brisas (Maritime and Terrestrial) and Wave Disturbances in the Trade Winds (POAS), in accordance with [17]. El Niño – Southern Oscillation (ENSO) is another mode of climate variability that influences the occurrence of NEB precipitation.

The process of accelerated urban growth is the subject of studies for the purpose of evaluating the dynamics of the landscape, due to the transformations that have taken place in recent decades in Brazil, from the process of integration of the interior regions of the country to the spread of industry towards medium-sized cities, according [12] District warming can be influenced by winds, low humidity and also by rising sea levels.

The reduction of precipitation in urban centers from the effects of natural climate variability and human-induced variability makes the climate warmer, making human and agricultural activities unfeasible, although there is some forecast of increased rainfall in the future. According to [10], the reduction in rainfall and flow in rivers will limit sewage and river transport, compromising water treatment and sanitary sewage plants. Energy generation will also be affected by the lack of rain and high rates of evaporation and evapotranspiration will occur due to warming in some regions.

The objective is to analyze the climatic oscillations of the meteorological and climatic elements, such as precipitation, days with occurrences of rains, insolation, relative humidity, cloud cover, intensity of the wind and the fluctuations of the maximum and minimum temperatures of the air in the municipality of Recife - PE, providing subsidies insurance for decision makers and municipal, state and federal authorities to carry out rural and urban planning, water supply and impoundment, energy generation, agriculture and irrigation, with a view to real and sustainable development.

2. Material and methods

Recife is among the three largest urban agglomerations in the Northeast. It occupies a central position, with a distance of around 800 km from the other metropolises, Salvador and Fortaleza, disputing with them the strategic space of influence in the Region. With a territorial area of 330 km2, it is limited to the north by the cities of Olinda and Paulista, to the south by the municipality of Jaboatão dos Guararapes, to the west by São Lourenço da Mata and Camaragibe, to the east by the Atlantic Ocean. According to data from the 2010 census, the City of Recife has a population of over two million inhabitants. Located at latitude 08º01'S; longitude 34º51'W, with an average altitude in relation to sea level of 72 m (Figure 1).

Source: Medeiros (2022)

Figure 1 Location of the city of Recife. Scale: 1: 10,000

The atmospheric systems that contribute to the precipitation of the Recife Metropolitan Region are the Frontal Systems, the Eastern Wave Disturbances and the Sea and Land Breezes, the latter being originated in the Atlantic Ocean. East Waves are common in autumn/winter, aided by the southeast trade winds. The Waves hit the eastern coast of the Northeast, causing heavy rains. The Intertropical Convergence Zone (CZIT) is one of the main rain-causing systems, a disturbance associated with the expansion towards the southern hemisphere of the thermal equator (zone of ascension of the trade winds by thermal convection). The CZIT reaches Recife, mainly in autumn, and causes rains with thunderstorms and changes in the direction of the winds from SE to NE, or even calms. The formations of the High Level Cyclone Vortex (ASVC) systems, in the months of February to April, have edges over the NEB, especially above the state of Pernambuco, increase cloud cover and cause moderate to heavy rainfall in short periods. Interval of time, causing damage to communities such as flooding, floods, floods and the socioeconomic sector.

The study of the spatial temporal behavior of daily and monthly rainfall, maximum and minimum temperatures, relative air humidity, insolation, cloud cover, wind intensity used was acquired from the National Institute of Meteorology (INMET), the data period comprises the series from 1962 to 2015.

The analysis of trends in the climatic variables of the city of Recife, which adopted the procedure of calculations of moving averages and calculations of linear regression tending to adjust the behavior of the historical series, which led them to make a pre-judgment of the eventual occurrence of its tendencies. The Kolmogorov-Smirnov (KS) test was used to verify the adequacy of the data to the probability distribution. The Weibull distribution was adjusted for annual insolation and relative air humidity and cloud cover.

For the plotting of the data and elaboration of the graphs and tables, the software was used in electronic spreadsheets. Data observed at synoptic times were used and descriptive statistical analyzes were applied (mean, standard deviation, calculation of absolute maximum and minimum values and coefficient of variance), in order to obtain more clarity regarding the results.

With the acquisition, collection and organization of the data, the mathematical and statistical models were developed, using a program with electronic spreadsheets. For statistical analyses, linear regression methods were applied, the regression coefficients obtained at the level of 5% were estimated, through moving averages, different probability distributions were used, chosen among the most frequently used, including Logistic, Log-Normal and Weibull, respectively, the cumulative probability density functions as described below:

$$P(x) = 1 - \exp\left(-\alpha x^{\beta}\right) \text{ (Weibull)}$$

$$P(x) = \frac{1}{1+exp\left\{-\frac{\pi(x-\mu)}{\sigma\sqrt{3}}\right\}}, x, \mu \in \mathbb{R}, \sigma > 0 \text{ (Logística)}$$

$$f(x) = \frac{1}{B(\alpha,\beta)} \frac{(x-c)^{\alpha-1}(d-x)^{\beta-1}}{(d-c)^{\alpha+\beta-1}}, com \alpha, \beta > 0, x \in [c,d] \qquad \text{(Beta4)}$$

The beta4 distribution was obtained by transforming a variable in such a way that the distribution occurred in an interval [c, d], where c and d could assume any value.

$$F(x) = \exp\left\{-\left[1+\xi\left(\frac{x-\mu}{\sigma}\right)\right]^{-\left(\frac{1}{\xi}\right)}\right\} \qquad \text{(GEV)}$$

Defined at -∞ < <μ - σ/ for < 0 and μ - σ/ < < ∞, where μ, σ ϴ are the position, scale and shape parameters respectively, with σ>0. The adjustments and selection of the best theoretical distributions were made using the Kolmogov-Smirnov test, which compares the accumulated empirical distributions with the theoretical ones. This test measures the maximum distance between the results of a share to be tested and the values associated with the hypothetically true one. The test statistic is given by D, representing the maximum difference between the theoretical (F(x)) and empirical (F(a)) accumulated probability functions. The test takes the following form:

$$D = máx|F(x) - F(a)|$$

The acceptance of the fit of the data to the intended function was demanding, since the significance level of 5% was considered. In this way, it was possible to infer if and when there is a trend in a certain historical series for the studied sample.

3. Results and discussion

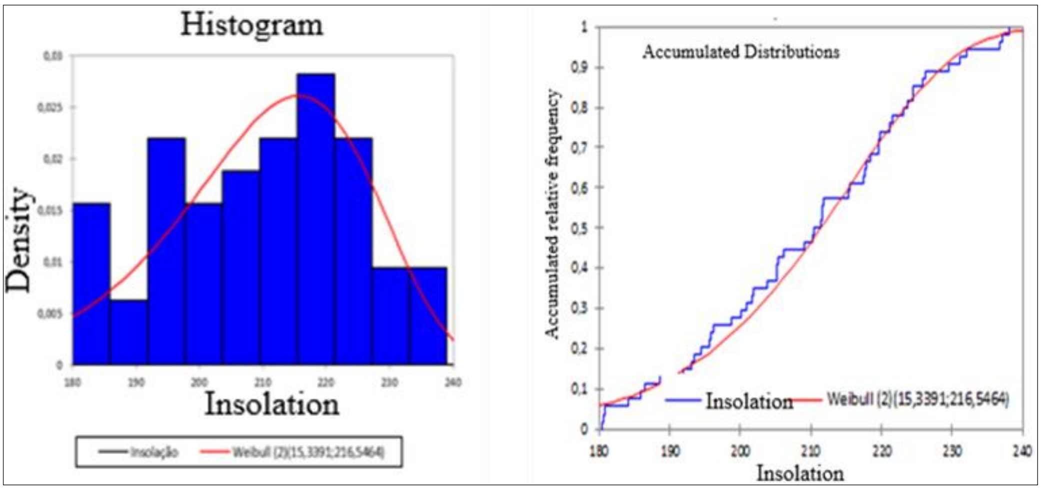
The tests showed that the Logistics distribution was the one that best fitted the data of total annual precipitation and annual minimum air temperature. The GEV distribution was adjusted to the wind intensity. The maximum annual air temperature was adjusted to the Normal distribution. The results of the different analyzes of the series studied show agreement between the applied statistical tests, which indicated significant changes in the series of annual data.

Table 1 Results of the Kolmogorov-Smirnov test and linear regression analysis in Recife - PE from 1962 to 2015

Analyzed Variables	Kolmogorov-Smirnov Test(P-value)	Angular coefficient
Annual heat stroke	0.95 (Weibull2)	-0.1226
Annual Relative Air Humidity	1.00 (Weibull2)	0.9156
Annual Precipitation	0.85 (Logística)	0.0843
Annual Maximum Air Temperature	0.82 (Normal)	-0.3444
Annual Minimum Air Temperature	0.81 (Logística)	-1.7056
Annual cloud coverage	0.90 (Weibull2)	-0.3936
wind intensity	0.1 (GEV)	-0.4784

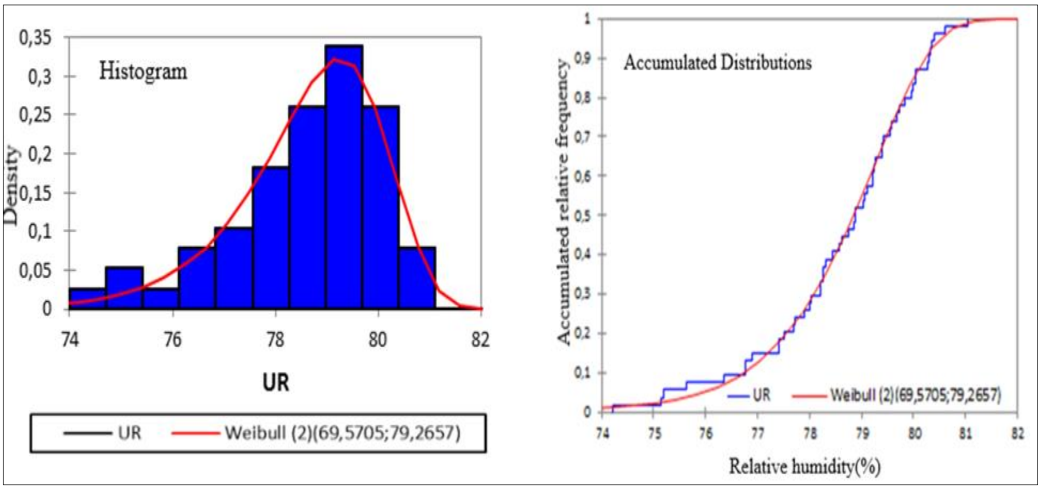
The Weibull Cumulative Probability Distribution for the variability of total insolation (Figure 2) showed a negative slope of 0.1226, with a KS significance test of 0.95.

The angular coefficient was positive at 0.9156, with a KS significance test, with a value of 1.00 for the variability of relative air humidity (Figure 3). They showed variability of greater occurrences between 78 to 80% with greater significance in the rainy season.



Source: Medeiros (2022)

Figure 2 Probability Density Function and Cumulative Distribution Function that best fitted the total insolation data in Recife - PE, from 1962 to 2015



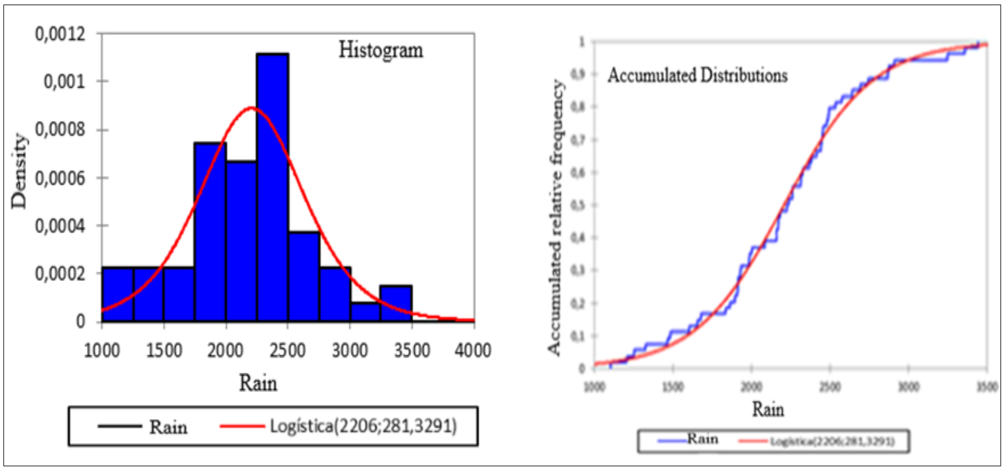
Source: Medeiros (2022)

Figure 3 Probability Density Function and Accumulated Distribution Function that best fitted the relative humidity data in Recife - PE, from 1962 to 2015

Comparing the results of relative air humidity in this study with other studies already carried out for the Northeast region of Brazil, similarities with the results of [14] were detected.

The KS significance test with a value of 0.85 is with a slope of 0.0843 for the total annual precipitation for the Logistic Cumulative Probability (Figure 4). They demonstrate irregular variability and trend of climate changes between the series studied. The logistic distribution shows greater probability of occurrence of rainfall between 2000 and 2500 mm where the median has greater reliability of occurrence.

The critical period of drought between the months of October, November, December and January, register the lowest average rainfall, causing the trend test to underestimate its indexes. In the months from April to July, which corresponds to the rainy season, the trend test predicts a higher degree of reliability. Since the test takes into account the average data, the rainy season was taken into account as the most significant.



Source: Medeiros (2022)

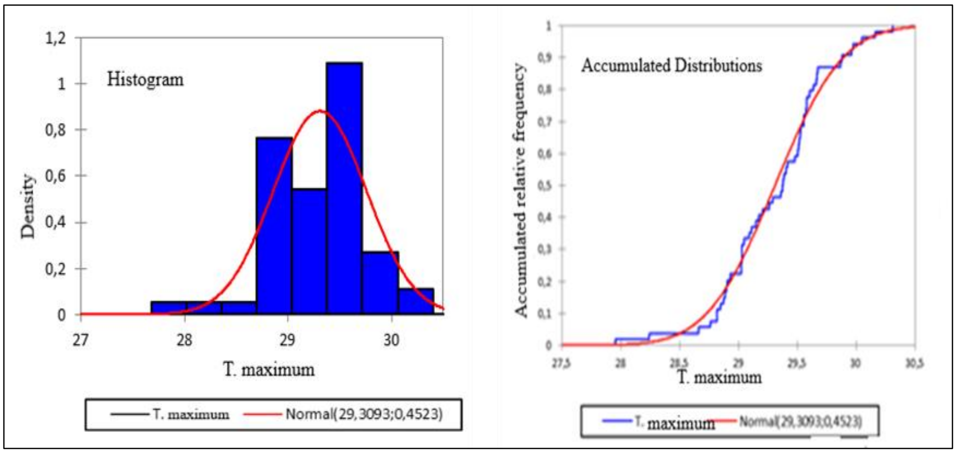
Figure 4 Probability density function and cumulative distribution function that best fitted the rainfall data in Recife - PE, from 1962 to 2015

Comparing the study with other studies carried out for the Northeast region of Brazil (NEB), analogies with the results of [16] and [10] were observed. The NEB region, mainly in the semi-arid portion, is periodically affected by the occurrence of droughts that compromise the water supply, and consequently the water recharge, mainly due to the irregularity of the rainy season in the region, with predominance of intense and short-lasting rains in accordance with [2].

The probability distribution function that best fitted the maximum and minimum temperature data was performed using the Kolmogorov-Smirnov (KS) test at the 5% probability level, using average temperature data from the 1962-2015 series.

The normal cumulative probability distribution for maximum temperature variability (figure 5) with a KS significance test is 0.82, and with a negative slope of 0.3444.

[15] found variability of maximum temperature increases with fluctuations greater than 30 °C for the municipalities of Bom Jesus and Parnaguá - Piauí. This result collaborates with those of the research carried out.



Source: Medeiros (2022).

Figure 5 Probability density function and cumulative distribution function that best fitted the maximum temperature data in Recife - PE, from 1962 to 2015

The logistic cumulative probability distribution for the minimum temperature variable (figure 6) with a KS significance test of 0.81 and a negative slope of -1.7056. In accordance with the tests described in Table 1, climatic variables with negative values are not likely to occur. The increase in fluctuations between 21 and 23°C in the studied series stands out.

Similar results were established by [15] who showed variability in minimum temperature increases in the dawn period, leaving dawns hotter than normal.

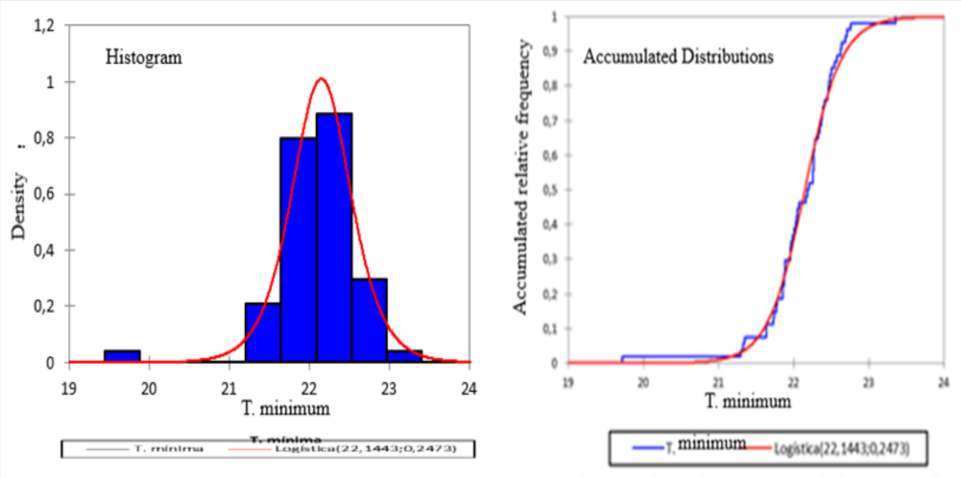


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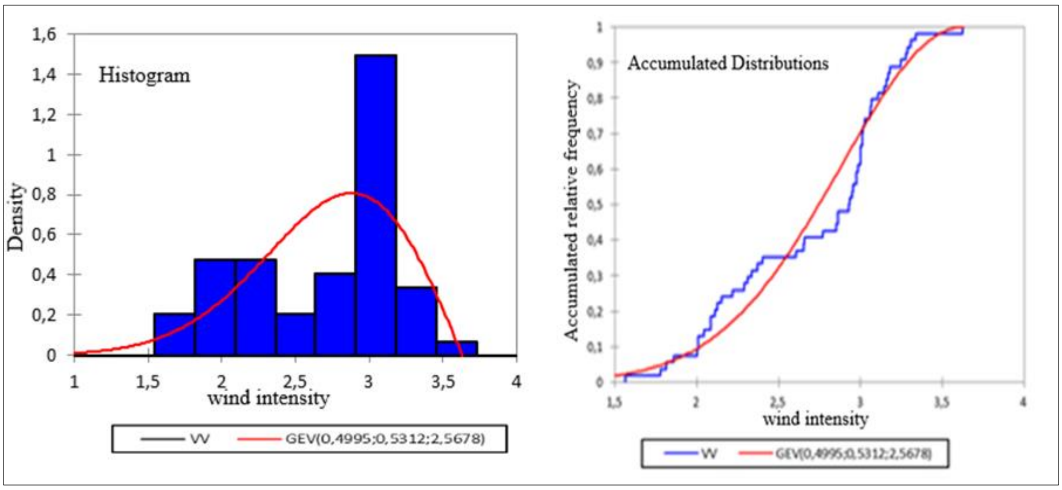
Figure 6 Probability Density Function and Cumulative Distribution Function that best fitted the minimum temperature data in Recife - PE, from 1962 to 2015

The KS significance test with a value of 0.1e with a negative slope of -0.4784 for the annual wind intensity for the GEV cumulative probability distribution (Figure 7). It is observed that the GEV probability distribution presents underestimated values in its tests. Such results were also found by [11] for the Cerrados area of Piauí.



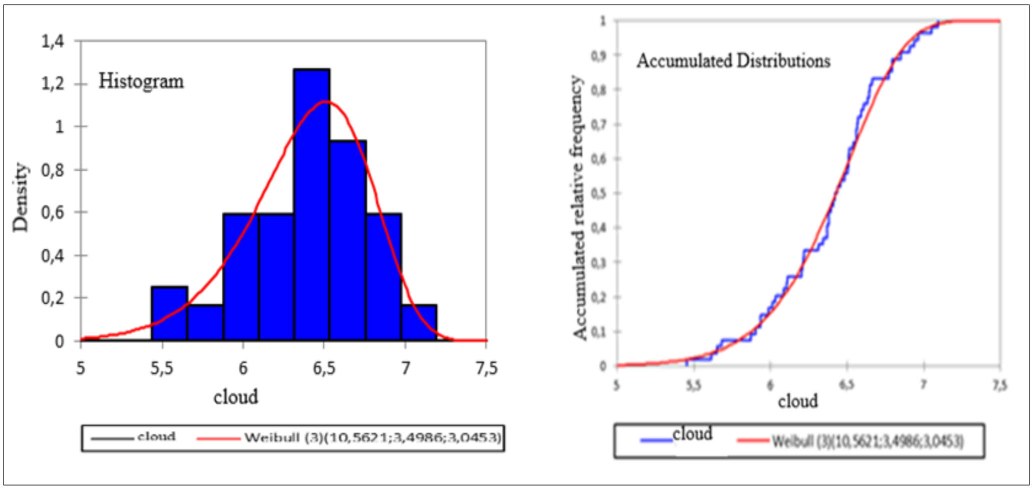
Source: Medeiros (2022)

Figure 7 Probability Density Function and Cumulative Distribution Function that best fitted the wind intensity data in Recife - PE, from 1962 to 2015

The Weibull Probability distribution for cloud coverage with significance test was 0.90 and slope of -0.3936 (Figure 8).

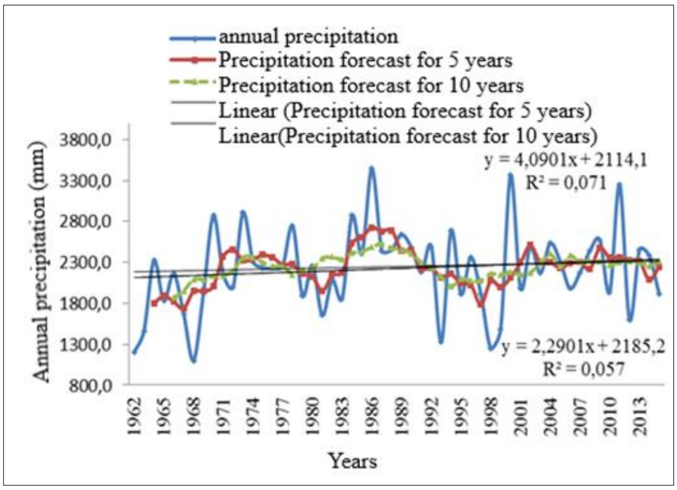
The critical period of drought between the months of October, November, December and January, register the lowest cloud cover, causing the trend test to underestimate its indices. In the months from April to July, which corresponds to the rainy season, the trend test predicts a higher significance level of reliability. Since the test takes into account the average data, the rainy season was taken into account, which helps in the greater cloud coverage, similar factors were found in the results of [10] and [14].

The variability of annual rainfall in Recife-PE and the variability of the moving average, with linear adjustments (Figure 9). There was an upward trend in rainfall for the period from 1962 to 2015. The linear equation (Figure 9) indicates a positive angular coefficient for the trends of 5 and 10 years and with a low level of significance. There is no expressive trend for the rainfall indices studied. Similar results were shown by [5].



Source: Medeiros (2022)

Figure 8 Probability density function and cumulative distribution function that best fitted the cloud coverage data in Recife - PE, from 1962 to 2015



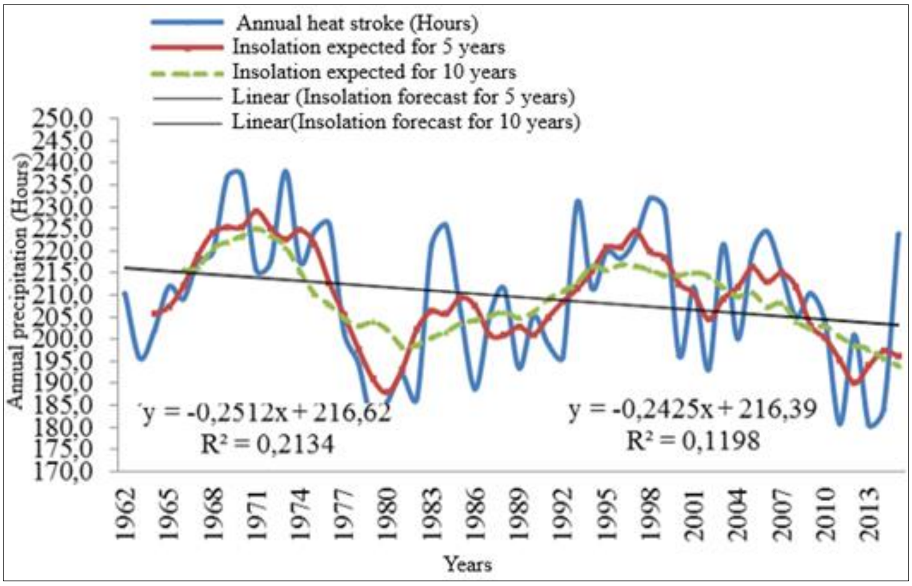
Source: Medeiros (2022)

Figure 9 Annual precipitation with the moving average of 5 and 10 years in Recife - PE, from 1962 to 2015

It is observed that there is linear adequacy in the moving averages with negative angular coefficient and with probability of occurrence of trend with reduction in the series of insolation data under study (Figure 10). The increase in the incidence of solar insolation can occur due to disordered civil constructions, such as vertical buildings above six floors, openings of new neighborhoods and invasions of slums without planning and survival structure, soil waterproofing, lack of afforestation, asphalt coverage that causes increase in thermal load, high incidence of automotive fleet and lack of natural wind circulation. The high incidence of insulation may harm no-tillage crops, affect human comfort. The increase in insolation in the study area is due to the lack of planning in urban areas. Such information was studied by [12].

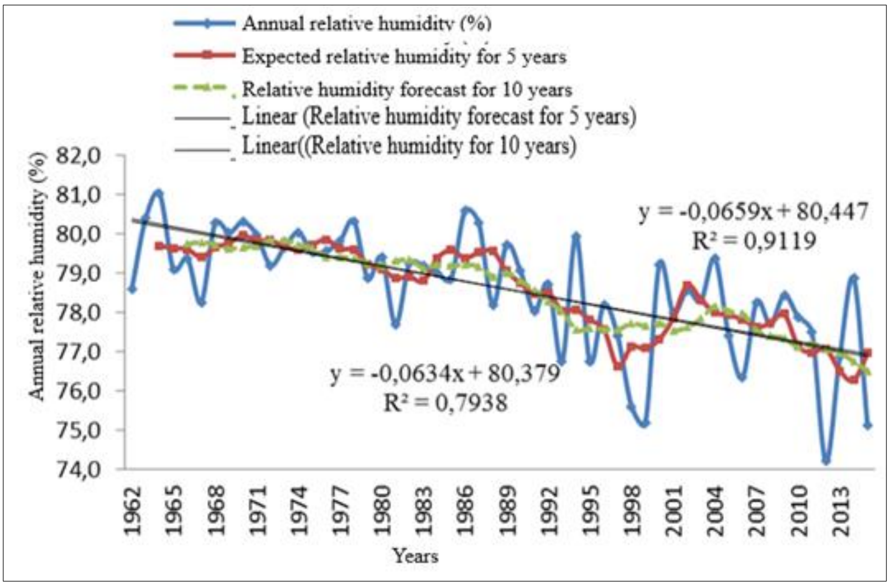
A decrease in relative air humidity is observed (Figure 11), because in urban areas, the high level of soil waterproofing, the deficiency of green areas, such as squares, tree-lined streets and avenues, availability of water on the surface, reduce heat exchange by evaporation and evapotranspiration, causing relative humidity levels to be reduced and most of the radiant energy used to heat the air. It reports that in the predicted relative humidity, there were significant reductions when compared to the real humidity, both in time and in magnitude for the next five and ten years.

Such variability showed consistency in the study of the average monthly and annual variation of relative air humidity in the Uruçuí Preto – Piauí river basin, in accordance with [11].



Source: Medeiros (2022)

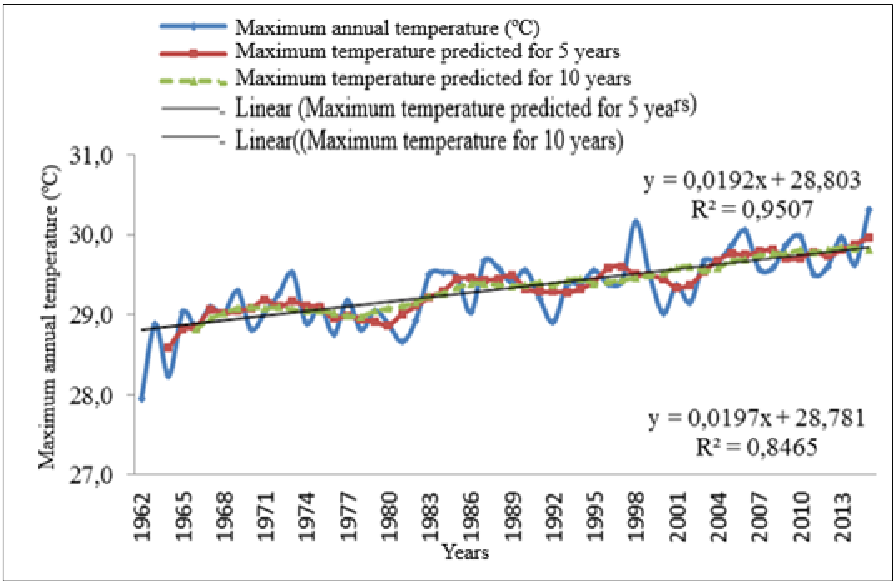
Figure 10 Total insolation with the moving average of 5 and 10 years in Recife - PE, from 1962 to 2015



Source: Medeiros (2022).

Figure 11 Relative humidity with the moving average of 5 and 10 years in Recife - PE, from 1962 to 2015

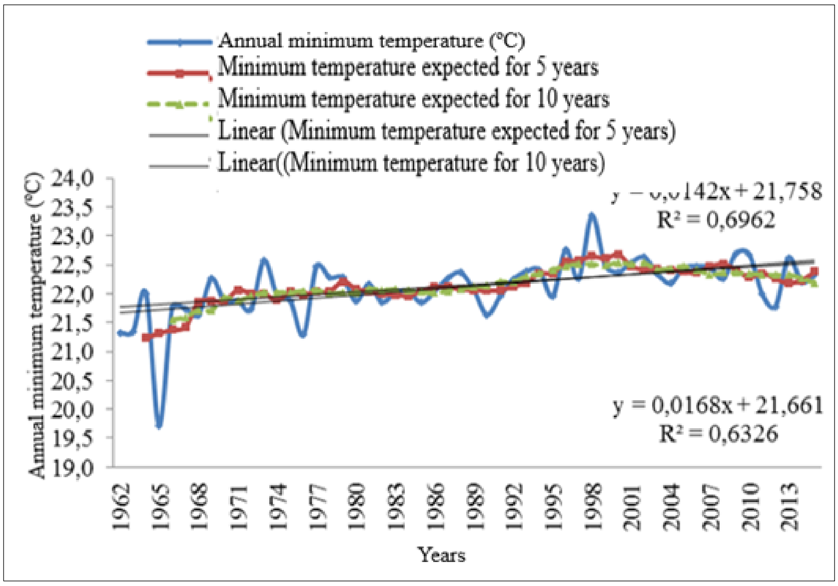
The actual and predicted maximum air temperatures show evidence of elevation, the slopes of the straight lines are positive. R^2 has high significance (Figure 12). In the 2000s, there was a tendency for an increase in the variability of the maximum annual air temperature. A study on the Uruçuí Preto river basin [12] presents similar values to the one studied



Source: Medeiros (2022)

Figure 12 Maximum temperature with the moving average of 5 and 10 years in Recife - PE, from 1962 to 2015

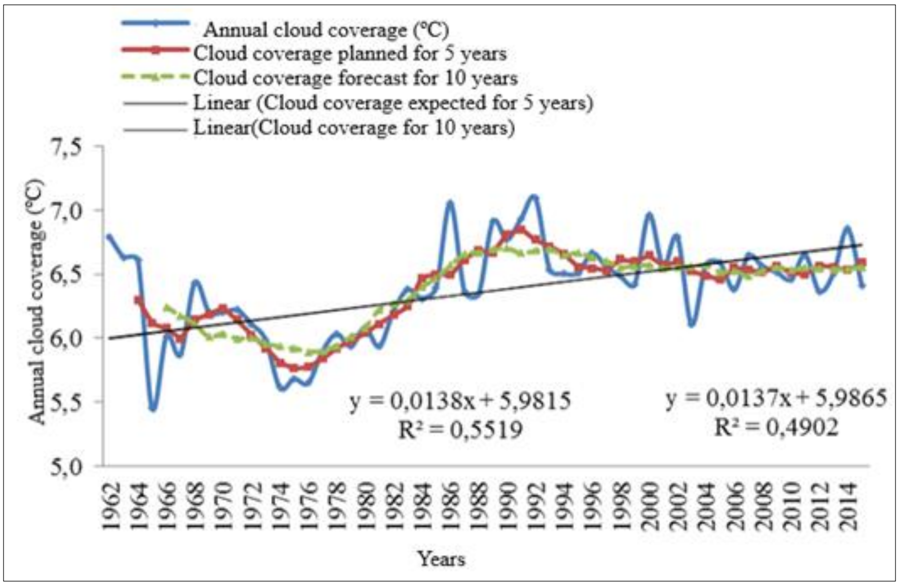
There is a significant linear increase in the annual minimum temperature and in the forecast (Figure 13). The slope is positive and R^2 has good significance. Based on observed trends, as well as studies carried out, considering future climate projections derived from climate models, the Intergovernmental Panel on Climate Change [7], it can be considered that the metropolitan region should become even warmer, with occurrences of inundations, inundations, inundations and landslides of slopes. Just like the dawn getting hotter. In agreement with the study by [10].



Source: Medeiros (2022)

Figure 13 Minimum temperature with the moving average of 5 and 10 years in Recife - PE, from 1962 to 2015

The tenth cloud cover has a positive angular coefficient and a close R value, not indicating a good correlation (Figure 14). An increase in cloud cover is expected, with a probability of extreme rainfall, in a short time interval and of high magnitude. These buoyancy are related to the results obtained by [12] for the Uruçuí Preto river basin area.

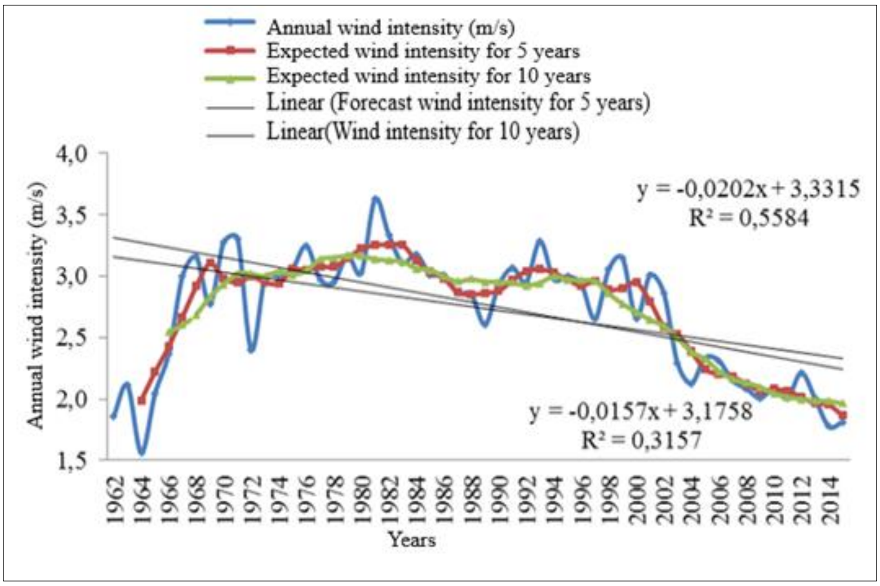


Source: Medeiros (2022)

Figure 14 Cloud coverage with the moving average of 5 and 10 years in Recife - PE, from 1962 to 2015

The wind intensity with the moving average of 5 and 10 years in Recife - PE in the period from 1962 to 2015 (Figure 15) has a negative angular coefficient, with trends of reduction in intensities, both actual and in the predicted intensities for five and ten years. R^2 has moderate significance, showing that the tendency of the wind is to suffer reduction, in accordance with [12] and [15]. Identical characteristics were recorded in the Uruçuí Preto river basin area.

The probability functions applied to the meteorological elements studied, as well as the fluctuations of the moving averages of 5 and 10 showed adequate significance to the local climate variability.



Source: Medeiros (2022)

Figure 15 Wind intensity with the moving average of 5 and 10 years in Recife - PE, from 1962 to 2015

4. Conclusion

The Weibull probability distribution showed a better fit to the elements insolation, relative air humidity and cloud cover. The Logistic distribution adjusted for precipitation and minimum temperature. The maximum temperature was more represented by the normal distribution and the wind intensity was adjusted to the GEV distribution.

Cumulative indications of precipitation were not detected with a view of increase and/or reduction in the area under study, but displacements of the rainy months were visualized.

Variability of maximum and minimum temperatures is observed, a fact that helps the process of desertification in the studied area. Correct flowering and, consequently, lead to low production.

The fluctuations in maximum and minimum temperatures record trends of increases caused by disproportionate asphalt implantations, removal of urban vegetation, high levels of CO_2 repelled by urban transport, soil compaction and lack of infrastructure in vertical growth.

The instabilities and/or stability of relative humidity, recorded in urban areas, when accompanied by high temperatures, produce an environmental discomfort that is difficult to describe through the physiological, emotional and behavioral reactions experienced by the population, not providing good thermal conditioning.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to disclosed. All authors had equal participation in the development of the article.

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