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ANALYSIS OF PRECIPITATION DATA FOR EVALUATION OF DRY AND RAINY EVENTS ON THE NORTH COAST OF THE STATE OF BAHIA

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ABSTRACT

This work aimed to contribute to the understanding of the climatic patterns of the North Coast of the State of Bahia and the development of strategies for adaptation and mitigation of dry and rainy climatic events. Data on rainfall, temperature, and relative humidity from 1991 to 2020 were analyzed. To carry out the analyses and to fill in the gaps in the data of the historical series, through kriging, the GS+ geostatistical analysis program was used. The results of this work showed that, even with the occurrence of climate change, it was not possible to observe significant changes in the precipitation pattern in the region, but with the analysis of the temperature, an increase was observed in the winter and summer months. From July 1991 to 2008, the temperature ranged from approximately 21.0 to 22.2 °C; however, from 2009 onwards, there was a continuous increase in temperature, reaching 23.0°C in 2020. Regarding humidity, there was a significant decrease in the winter months, from 91.0% in July 1991 to 89.0% in July 2020. Such results were related to the Sustainable Development Goals - SDG 06 drinking water and sanitation and 13 action against global climate change.

Keywords: Climatic events. North Coast of Bahia. Precipitation. Temperature. Moisture.

INTRODUCTION

According to the Intergovernmental Panel on Climate Change (IPCC, human-caused climate change is already affecting many meteorological and climate extremes around the world. Extreme weather events, droughts or floods, have significant importance in the daily life of society, either because of their frequency and intensity of occurrence or because of the socio-environmental vulnerability of a considerable part of society (CAMPOS; SANTOS, 2017).

In the case of major floods, the establishment of the extreme situation is immediately visible due to the impact on watercourses, with flooding mainly affecting cities and agricultural areas. However, in the case of drought, it is more difficult to perceive that something is happening, given that drought settles slowly and impacts water resources

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gradually (DIAS, 2014).

The early detection of signs of climatic extremes, dry and rainy, as well as their follow-up, are based on an immense set of information from the most varied sectors and constitute one of the highest priority subjects for research and development today, given that such events impact the economies of countries, produce fatalities and damage to infrastructure and the environment (DIAS, 2014).

The region of the North Coast of the State of Bahia is characterized by great climatic variability, influenced by the proximity to the Atlantic Ocean and the presence of different biomes, such as mangroves, sandbanks, Atlantic Forest, and Caatinga. In this context, precipitation is a key climatic element that directly affects water availability, agriculture, public health, and other socioeconomic aspects of the region. Therefore, the research aimed to contribute to the understanding of local weather patterns and to the development of strategies for adapting to and mitigating dry and rainy weather events.

Given the above, this work proposes an analysis of rainfall data in the North Coast region of the State of Bahia, aiming to evaluate the occurrence of dry and rainy events. In addition to precipitation, other climatic elements, such as temperature and humidity, were considered, as these factors have a direct influence on rainfall formation. In addition, the results found were related to the Sustainable Development Goals (SDGs).

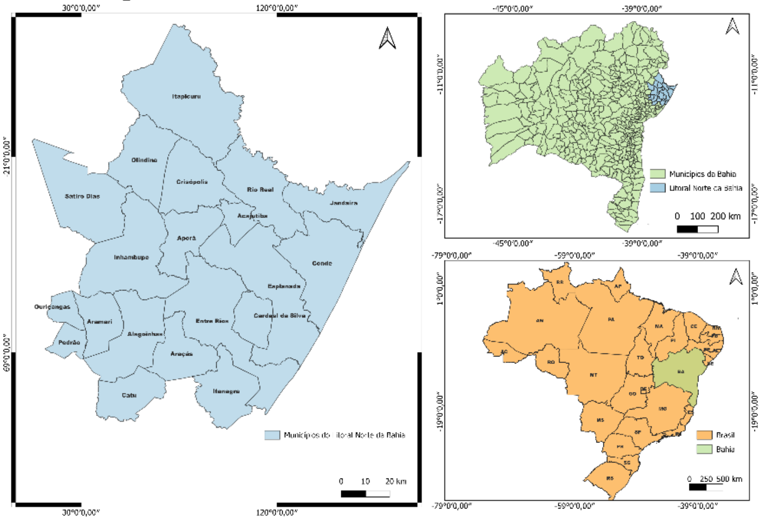
METHODOLOGY

FIELD OF STUDY

The North Coast of Bahia is located mostly in the Northeast of Bahia (Figure 1), between the approximate coordinates of 10°51' to 12°27' S and 37°19' to 38°46' W, occupies an area of 13,594 km2, which corresponds to 2.4% of the size of Bahia, has 541,332 inhabitants and is composed of 20 municipalities: Acajutiba, Itapicuru, Crisópolis, Olindina, Sátiro Dias, Aporá, Inhambupe, Ouriçangas, Pedrão, Aramari, Rio Real, Jandaíra, Conde, Esplanada, Cardeal da Silva, Entre Rios, Araçás, Alagoinhas, Catu and Itanagra. The territory in question is confronted with four others, namely the Metropolitan Territory of Salvador, Portal do Sertão Territory, Sisal Territory, and Northeast Semi-Arid Territory II. In addition, it borders the State of Sergipe (BAHIA, 2017; SEI, 2023b; SEI, 2022; SEI, 2016).

Also according to the Superintendence of Economic and Social Studies - SEI (2016), the North Coast is crossed by important highways, the most prominent being the BR-101, which crosses the headquarters of the municipalities of Alagoinhas, Entre Rios and Esplanada, is the main connection between the internal part of the territory, the state capital and other regions. In addition to this, the BR-110, BA-099 and BA-093 also play important roles, whether in the flow of the territory's production (oil, beer, lemon, tangerine, orange, beans, corn, among others), in tourist tours in the region, in access to the production units of the Camaçari Petrochemical Complex or as access routes to other municipal headquarters.

Figure 1: Location of the North Coast of Bahia.



Sistemas de Coordenadas Geográficas; Datum SIRGAS 2000; Bases Cartográficas IBGE, 2022.

Source: prepared by the authors.

The Gross Domestic Product - GDP of the North Coast, in 2020, was approximately R$10.1 billion, which represented 3.3% of the total GDP of the state, with the trade and services sector having the largest share with 63.9%, followed by industry with 18.4%. The GDP per capita was R$ 16,968.31. In this period, the highest GDP was recorded in Alagoinhas (44.1%), followed by Rio Real (9.7%), Catu (6.0%), and Esplanada (5.8%). The lowest GDPs were in the municipalities of Pedrão (0.5%), Ouriçangas (0.6%), and Itanagra (0.7%). In 2021, the GDP of this territory was R$ 10.93 billion, representing 3.1% of the total of the state of Bahia (SEI, 2023b; SEI, 2023a). Among the most relevant activities in this territory is tourism, driven by the natural beauty of the North Coast of Bahia, attracting significant investments in infrastructure, such as hotels, resorts, and luxury condominiums, among others. Agricultural production resulted in R$ 664.2 million in 2021, with the main products being oranges (R$ 293.0 million, 85% of Bahia's production), cassava (R$ 79.4 million, 15.3% of Bahia's production) and corn (R$ 121.4 million, 5.3% of Bahia's production) (BAHIA, 2015; SEI, 2023a).

CLIMATIC CHARACTERIZATION OF THE STUDY AREA

The climatic diversity in this region is wide, as it ranges from humid to subhumid tropical climate, humid (between Conde and Itanagra), subhumid to dry and even semi-arid

(Inhambupe, Sátiro Dias, Crisópolis, Olindina and Itapicuru) which ends up reflecting on the rainfall regime that can oscillate from 500 to 800 mm in the most arid areas and up to 2,000 mm in the most humid regions. There are two predominant biomes: the Caatinga and, on a larger scale, the Atlantic Forest (BAHIA, 2015).

As a result of its latitudinal location, the North Coast of Bahia has high levels of humidity and rainfall. The circulation model is characterized by the presence of southeast trade winds, which act for most of the year, and frontal systems that cause cold fronts in autumn and winter. Temperature values range from 22.0 to 27.0°C (NETTO, 2017).

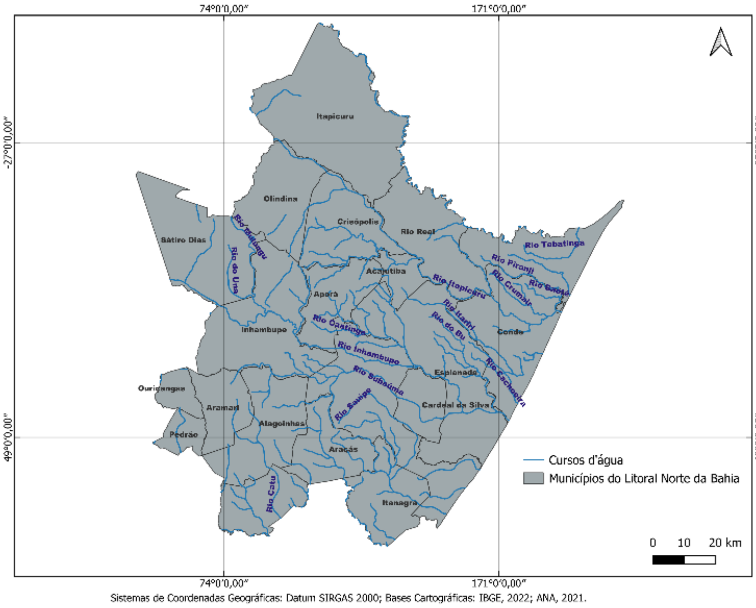
The atmospheric circulation pattern of the Brazilian Northeast is composed of three main elements, namely: air masses originating in the South Atlantic High Pressure cell, the semi-periodic advance of Atlantic Polar Front masses (which results in precipitation in the form of rainfall) and the Intertropical Convergence Zone - ITCZ, which is defined as a band of clouds that surrounds the equatorial belt, formed by the confluence of the trade winds of the northern and southern hemispheres, at low levels, low pressures, high sea surface temperatures, intense convective activity and precipitation. The ITCZ is the most relevant factor in determining the volume of rainfall in the northern sector of Northeast Brazil Dominguez, 1992) apud (NETTO, 2017). About the relationship between these systems, the following is available:

> When North Atlantic waters are cooler than normal, the North Atlantic High Pressure System and northeast trade winds intensify. If, in this same period, the South Atlantic is warmer than normal, the South Atlantic High Pressure System and the southeast trade winds weaken. This pattern favors the displacement of the ITCZ to positions further south of the equator, and is conducive to the occurrence of normal, rainy or very rainy years for the northern sector of Northeast Brazil [...] when the waters of the South Atlantic are colder than normal, the South Atlantic High Pressure System and the southeast trade winds intensify. If, in this same period, the waters in the North Atlantic are warmer than normal, the North Atlantic High Pressure System and the northeast trade winds weaken. This pattern favors the displacement of the ITCZ to positions further north of the equator and is conducive to the occurrence of dry or very dry years for the northern sector of Northeast Brazil (FERREIRA; MELLO, 2005).

Also, according to these authors, the monitoring of ocean and atmospheric patterns during the rainy season is essential so that weather and climate forecasts can be generated with a higher degree of reliability.

According to SEI (2016), in addition to the Recôncavo Norte Hydrographic Basin, the basins of the Inhambupe, Itapicuru, and Real Rivers are part of this territory. The hydrographic network is more concentrated in the eastern potion, where the coastal municipalities are located. The main rivers are Aramari, Cachoeira, Catu, das Piabas, das Pontes, Imbassaí, Inhambupe, Itapicuru, Itariri, Pitanga, Pojuca, Quiricó Grande, Quiricó Pequeno, Real, Sauípe, and Subaúma, some of which are shown in Figure 2.

Figure 2: Location of the main rivers.



Source: prepared by the authors.

MATERIALS

For the development of this work, historical rainfall data from 45 stations available in 18 municipalities on the North Coast of Bahia, in the period from 1991 to 2020, totaling 30 years of data, which corresponds to a climatological normal, were obtained through the Hidroweb website of the National Information System of the National Water Agency - ANA. Table 1 shows the rainfall stations in which data were collected.

Table 1: Rainfall stations on the North Coast of Bahia and their respective codes.

No.	Season	Code	Latitude	Longitude
1	Acajutiba	1137042	-11,655	-37,937
2	Alagoinhas	1238005	-12,133	-38,417
3	Alagoinhas	1238006	-12,149	-38,424
4	Alagoinhas	1238037	-12,133	-38,417
5	Alagoinhas	1238038	-12,133	-38,417
6	Alagoinhas	1238042	-12,251	-38,515
7	Aporá	1639020		
8	Araçás	1238010	-12,210	-38,201
9	Cardinal da Silva	1237001	-12,133	-37,967
10	Cardinal da Silva	1237003	-12,130	-37,942
11	Catu	1238002	-12,359	-38,374
12	Catu	1238003	-12,367	-38,383
13	Catu	1238054	-12,367	-38,383
14	Count	1137029	-11,813	-37,611
15	Count	1137031	-11,767	-37,817
16	Count	1137039	-11,767	-37,817
17	Count	1137043	-11,768	-37,804
18	Count	1137044	-11,812	-37,616
19	Chrysopolis	1138027	-11,509	-38,119
20	Entre Rios	1138008	-11,943	-38,084
21	Entre Rios	1138018	-11,917	-38,067
22	Entre Rios	1138022	-11,917	-38,067
23	Entre Rios	1239027	-12,000	-39,000

24	Terrace	1137028	-11,783	-37,950
25	Terrace	1137030	-11,750	-37,967
26	Terrace	1237000	-12,058	-37,756
27	Terrace	1237002	-12,066	-37,719
28	Inhambupe	1138002	-11,783	-38,348
29	Inhambupe	1138003	-11,783	-38,350
30	Itanagra	1238014	-12,263	-38,037
31	Itanagra	1238015	-12,291	-38,067
32	Itapicuru	1038013	-10,980	-38,180
33	Itapicuru	1137041	-11,600	-37,950
34	Itapicuru	1138006	-11,300	-38,217
35	Itapicuru	1138031	-11,319	-38,224
36	Jandaíra	1137027	-11,542	-37,566
37	Olindina	1138024	-11,417	-38,417
38	Olindina	1138030	-11,342	-38,318
39	Olindina	1138032	-11,453	-38,454
40	Ouriçangas	1138004	-11,933	-38,617
41	Ouriçangas	1138019	-11,946	-38,631
42	Rio Real	1137032	-11,467	-37,933
43	Rio Real	1137033	-11,467	-37,933
44	Rio Real	1137034	-11,467	-37,933
45	Sátiro Dias	1138016	-11,583	-38,583

Source: prepared by the author.

After collecting and selecting the data from the rainfall stations, it was possible to identify and discard those whose data were not sufficient for this study, the following exclusion criteria were adopted: series with total absence of data in the period considered, series with more than 8 years without continuous data and series with gaps of more than two years between the data. Thus, Table 2 shows the stations that were effectively used to generate the results of this work.

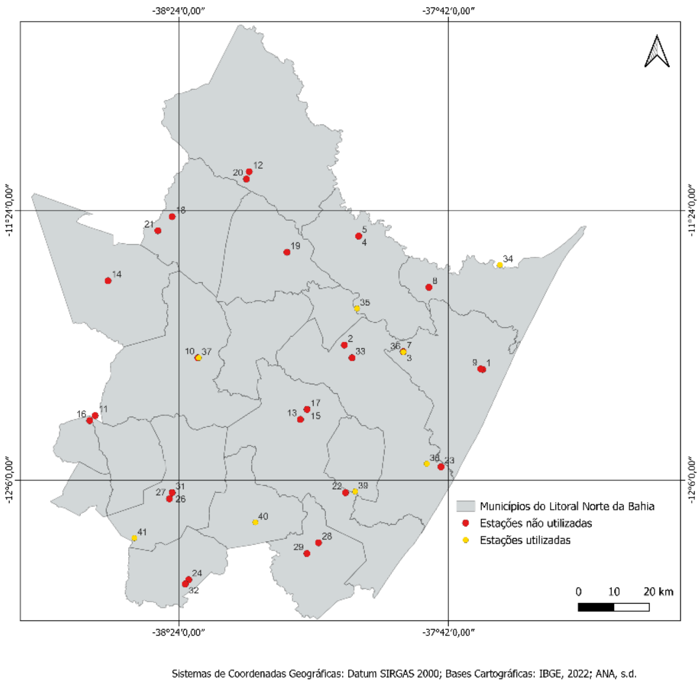
Table 2: Rainfall stations used.

No.	Season	Code	Latitude	Longitude
1	Acajutiba	1137042	-11,655	-37,937
2	Alagoinhas	1238042	-12,251	-38,515
3	Araçás	1238010	-12,210	-38,201
4	Cardinal da Silva	1237003	-12,130	-37,942
5	Count	1137043	-11,768	-37,804
6	Terrace	1237000	-12,058	-37,756
7	Inhambupe	1138002	-11,783	-38,348
8	Jandaíra	1137027	-11,542	-37,566

Source: prepared by the author.

Therefore, 8 rainfall stations were used, and two municipalities in the study area do not have stations, Aramari and Pedrão. The location of the used and unused stations is shown in Figure 3.

Figure 3: Spatial location of used and unused stations.



Source: prepared by the authors.

The complementary climatic data, temperature, and relative humidity of the air were obtained from the INMET website (s.db), in the Climatological Normals 1991-2020 tab, Alagoinhas station, code 83249, and the choice of this station was due to the absence of other climatological stations within the study area.

STATISTICAL AND GEOSPATIAL ANALYSIS SOFTWARE

The GS+ software was used to fill in the data of the historical series through spatial and temporal kriging. GS+ is a geostatistical analysis program that allows measuring and illustrating spatial relationships in georeferenced data, in addition to generating statistically accurate maps of the sampled area (ROBERTSON, 2008).

Therefore, the input data with coordinates were divided into X, Y, and Z, which correspond to the month, year, and the monthly precipitation for this month and this year, respectively. For the temperature and humidity data, this procedure was also done.

METHODS

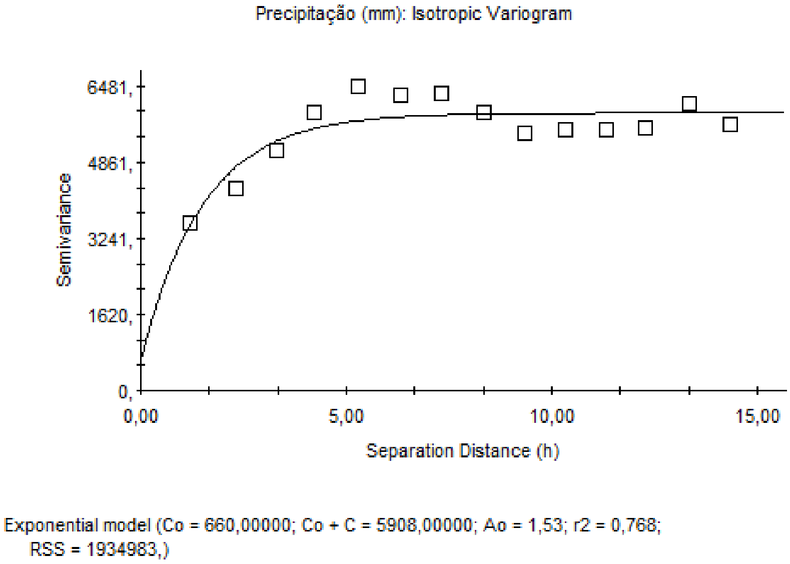
According to ROCHA et al. (2021), the kriging estimate is nothing more than the weighting of the samples contained in the vicinity of the point that is to be estimated. The weights are a function of the spatial variance that the spatial phenomenon presents.

The difference between kriging and other interpolation methods lies mainly in the way weights are assigned to different samples. In simple linear interpolation, the weights are all equal to 1/N (N=number of samples), while in the case of interpolation based on the inverse square of the distances, the weights are defined according to this alternative using the distance that separates the interpolated value from the observed values. In the case of kriging, the weights are determined from a spatial analysis, based on the experimental semivariogram. In addition, kriging provides, on average, non-biased estimates with minimal variance and is perhaps the most notable method of interpolation (MATOS, 2005).

RESULTS

In Figure 4 it is possible to verify the semivariogram generated by the GS+ software with the exponential medelum to fill in the gaps of the missing data, at this moment the r 2 was analyzed, which is the coefficient of determination, and the closer to 1, the lower the influence of variables external to the model. In this case, the r 2 obtained was 0.768, a value considered satisfactory, according to VILANOVA (2014).

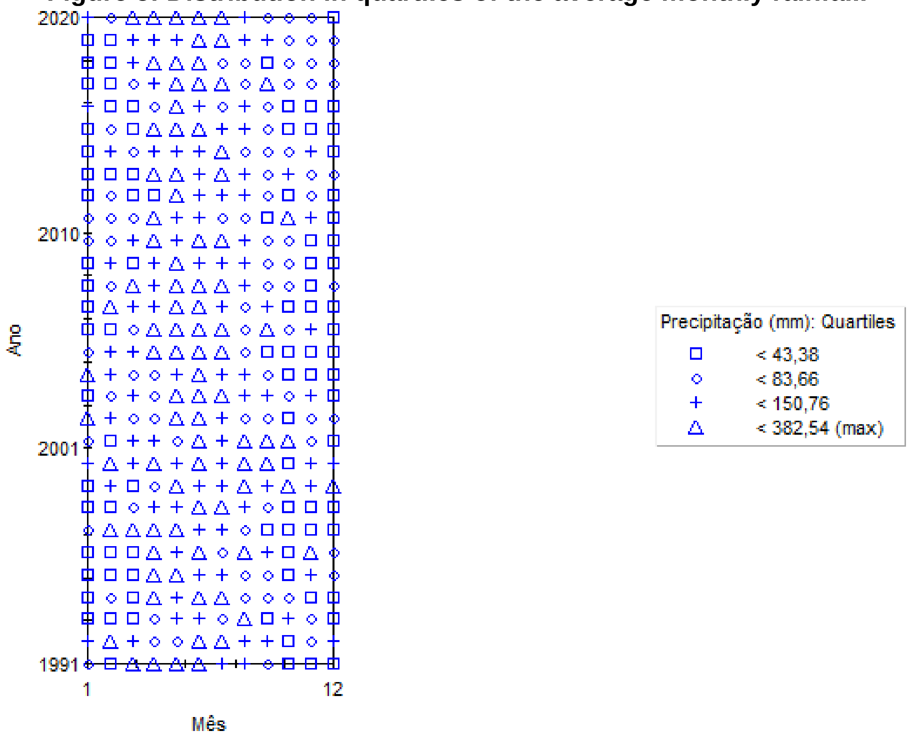
Figure 4: Semivariogram.



Source: prepared by the authors.

In Figure 5, it is possible to see that, in general, the behavior of the average monthly precipitation follows a pattern throughout the months and years, with June, July, and August being the months with the highest rainfall since it is the winter period. The lowest rainfall corresponds to December and January, summer.

Figure 5: Distribution in quartiles of the average monthly rainfall.



Source: prepared by the authors.

In the graph represented by Figure 6, it can be seen that, as the winter months (June, July, and August) approach, as mentioned above, the greater precipitation is proven by the darkening of the color scale. It is also possible to verify that November, December, January, and February are the months with the lowest rainfall.

Still analyzing this graph, it was found that in January 2004, there was an extreme precipitation event, with an average of 230 mm. According to ALVES et al. (2004), in that month, the northeast trade winds became more intense than the southeastern trade winds, driving ITCZ to reach the northern sector of the Brazilian Northeast, as well as an anomalous transport of moisture from the Amazon and the Atlantic Ocean in the lower troposphere. This thermodynamic pattern favored an intensification in the South Atlantic Convergence Zone - SACZ, allowing greater penetrations of cold fronts from southeastern Brazil to remain further north of the Brazilian Northeast.

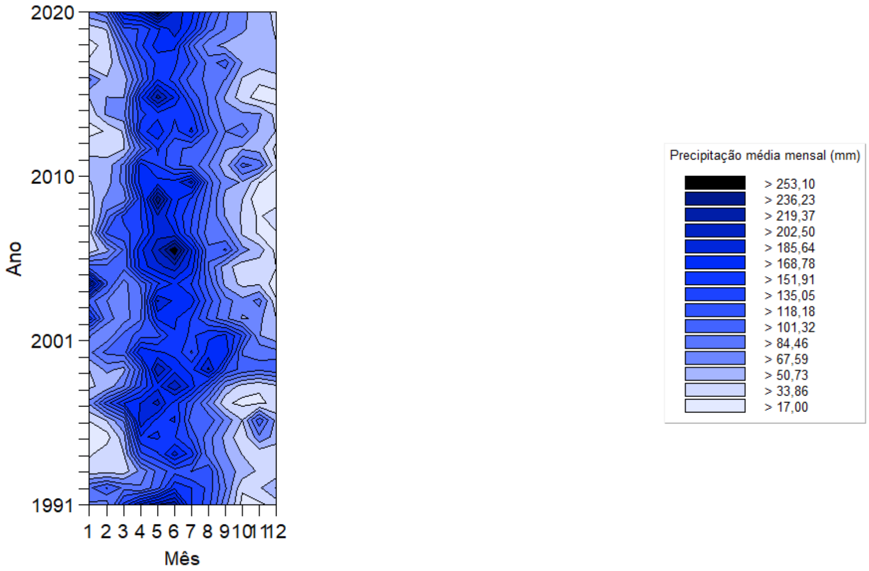
Another extreme precipitation event was observed in June 2006, with an average rainfall of 268 mm. According to SANTOS et al.. (2012), this event was characterized by areas of deep convection caused by a wave that reached the east coast of Northeast Brazil after propagating westward over the South Atlantic with an estimated phase velocity of 10 m $^{s-1}$.

In May 2020, another extreme precipitation event was observed. According to the Institute of the Environment and Water Resources (INEMA, 2020), throughout this period, significant accumulations of precipitation were observed in much of the Recôncavo and

Northeast, where volumes exceeded 300 mm above average in some locations. In some parts of the North, West, and Far South, above-average volumes were also observed. In the other regions of Bahia, the volumes of rain were close to normal.

In general, it is possible to see that over the years, even with climate change, rainfall intensity has not suffered drastic variations in this study area, considering only 2006, 2004, and 2020.

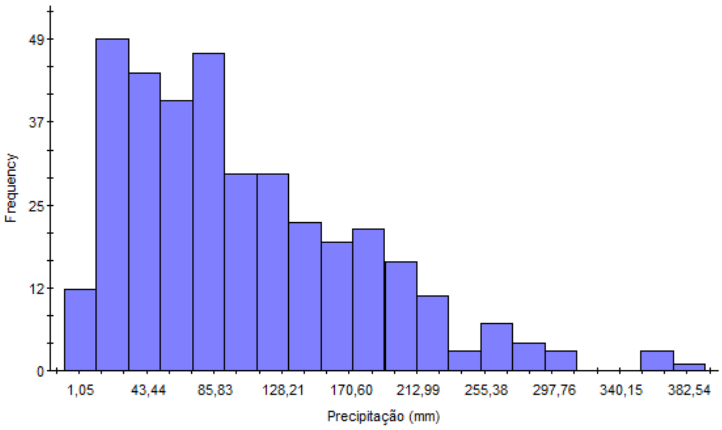
Figure 6: 2D graph of the average monthly rainfall of the municipalities under analysis in the period from 1991 to 2020.



Source: prepared by the authors.

Analyzing the frequency distribution graph in Figure 7, it is possible to see that the frequency distribution of the values is mostly concentrated in a range of 1.05 to 170.60mm, with higher values in a smaller occurrence and with extreme values with such a low occurrence that they would not even be able to be represented in the frequency distribution graph.

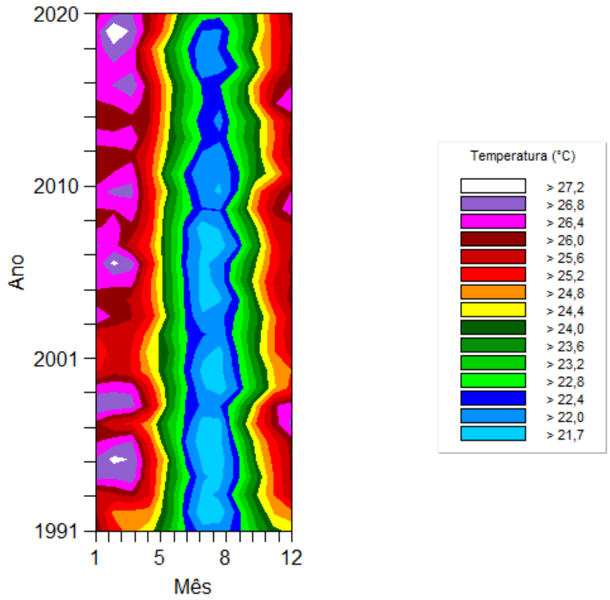
Figure 7: Frequency distribution.



Source: prepared by the authors.

Analyzing the graph represented in Figure 8, it is possible to notice a trend of increase in temperature in the cold months, especially in July, for that month the temperature, from 1991 to 2008, ranged from 21.0 to 22.2 °C, approximately, however, from 2009 onwards there was a continuous increase in temperature, reaching 23.0°C in 2020, This is evident in the graph as the color scale goes from blue to green.

Figure 8: 2D graph of the average monthly temperature of the municipality of Alagoinhas-BA in the period from 1991 to 2020.

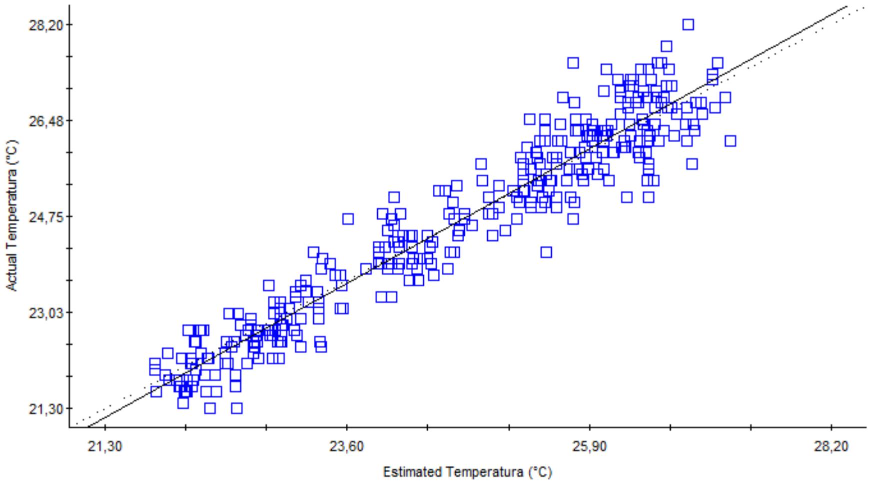


Source: prepared by the authors.

Analyzing the summer months, it was found that in the same period that there was an increase in temperature in the winter months, there was also an increase in the summer months, especially the month of February. Analyzing the color scale of the graph for that month, it can be seen that from 2009 onwards, there is a predominance of lilac, purple, and white colors, which represent the highest temperatures. It is also possible to highlight the month of February 2019 with a temperature of 27.6°C.

As shown in Figure 9, the value of r2 for the temperature data was 0.917, a value considered satisfactory, indicating that the regression of 91.7% of the observed values can be explained by the regression model.

Figure 9: Scatter plot of the mean temperature values.

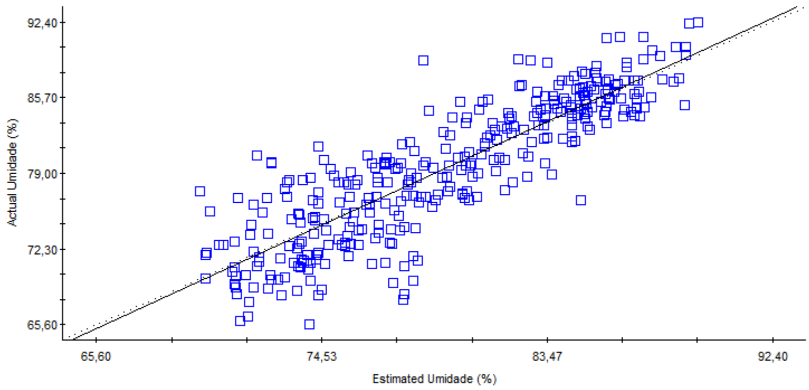


Regression coefficient = 1,049 (SE = 0,017 , r2 =0,917,
y intercept = -1,19, SE Prediction = 0,505)

Source: prepared by the authors.

According to the graph shown in Figure 10, the value of r2 for the relative humidity data was 0.744, a value considered satisfactory and indicating that 74.4% of the observed values can be explained by the regression model.

Figure 10: Scatter plot of relative humidity values.

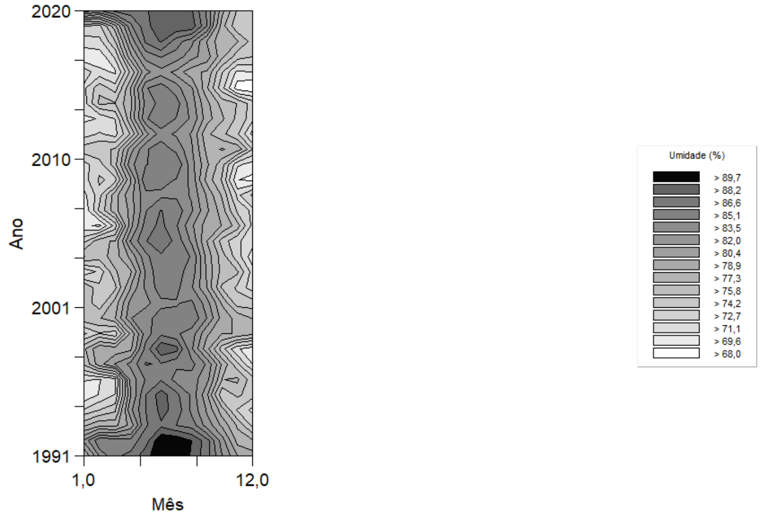


Regression coefficient = 1,024 (SE = 0,033 , r2 =0,744,
y intercept = -1,87, SE Prediction = 3,067)

Source: prepared by the authors.

Looking at the graph represented in Figure 11, it can be seen that, in an inverse way of temperature, there is a reduction in the relative humidity of the air in the winter months (June, July, and August).

Figure 11: 2D graph of the relative humidity of the air in the Municipality of Alagoinhas-BA in the period from 1991 to 2020.



Source: prepared by the authors.

Over the years, it went from 91.0% in July 1991, 85.75% in July 2010, and 89.0% in July 2020.

DISCUSSION

Relating the results found with SDGs 06 and 13, it is clear that the multiplication of dry and rainy events, changes in precipitation patterns, river flow, and water quality are undeniable. In addition, the effects on water availability increase society's insecurity and the challenges of public management, given the increase in the occurrence of floods, landslides, and economic and social losses that more directly affect the poor population. Therefore, reducing risks and increasing the ability to adapt to these new climate conditions is essential in the coming years (JACOBI & TRANI, 2019).

According to ARTAXO (2019), each city needs to have its flood fighting strategy, taking into account that water availability has important regional aspects. However, Brazilian cities were not planned to cope with climate extremes, droughts, or floods.

Also, according to this author, the implementation of each of the 17 SDGs will require unprecedented efforts on the part of society and the government. However, SDGs 13, 06, 07, 09, and 11 are part of a group that will require effective public policies and implemented in a way that is consistent with the geographical and administrative scales. None of the other SDGs will be achieved if SDG 13 is not, given its overwhelming effects on humanity and the biosphere (MARQUE, 2019).

If, on the one hand, the Federal Government and some state governments seek to develop public policies aimed at reducing greenhouse gases and adapting to climate change, many municipalities are unable to act efficiently, especially small municipalities, since they lack both financial resources and technical training. Therefore, the federal government and state governments must work with small municipalities to help them develop and execute adaptation plans (CÔRTES; NADRUZ, 2019).

CONCLUSION

The North Coast region of the State of Bahia is characterized by great climatic variability, influenced by the proximity to the Atlantic Ocean and the presence of different biomes, so it is essential to study dry and rainy climatic events in the region. Thus, the results of this work showed that, even with the occurrence of climate change, it was not possible to observe significant changes in the precipitation pattern in the region in the period under analysis. However, when it comes to temperature, it was possible to observe an upward trend in the winter and summer months. From July 1991 to 2008, the temperature ranged from 21.0 to 22.2 °C, approximately. However, from 2009 onwards, a continuous increase in temperature was observed, reaching 23.0°C in 2020, an increase of approximately 0.8°C. Regarding humidity, there was a significant decrease in the winter months, from 91.0% in July 1991 to 89.0% in July 2020, corresponding to a 2.0% reduction.

Even if the observed changes are considered small, it is necessary to carry out continuous monitoring to be able to predict the occurrence of dry and rainy events, but for this it is necessary to improve and increase the network of necessary equipment, given the difficulty of obtaining results with small margins of error for these forecasts due to climate variability. In addition, for all 17 SDGs to be achieved, especially SDG 13, it will be necessary for the Government to unite so that they encourage municipalities to plan and execute effective local and regional actions for mitigation and prevention, involving the most diverse actors in society and all civil society doing their part.

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