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Climatic characterization of the Damují hydrographic basin

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Abstract: Watersheds play an important role in supplying water to the agricultural sector, as well as other economic, social, and environmental activities in the province. Climate knowledge is of great importance for the sustainable development of any study area, so the objective of this research is to climatically characterize the Damují River Basin. This study used preliminary results from the Agroclimatic Atlas of Cienfuegos Province, the digital database of all meteorological variables from 62 meteorological stations belonging to the Institute of Meteorology Network, and the 4x4 km grid previously used in other climate and agrometeorological studies, taking the 1991-2020 period as the standard climate period. The average annual temperature in the basin does not experience significant spatial variation, with values between 24 and 25° C across most of its surface, increasing slightly in the southern portion with records between 25 and 26° C. Minimum temperatures in December, January, and February can average below 16° C, and maximum temperatures can exceed 31° C on average in the northern half of the study area. However, in July and August, temperatures can exceed 33.5° C on average. Annual cumulative rainfall totals 1,422.1 mm. The information generated provides a tool for decision-makers to adapt and address climate change and variability with greater knowledge.

Key words: hydrographic basin; temperature; precipitation; climate variability

1 Introduction

The study of climate is fundamental in the scope of a river basin since it is the main factor of alteration of the environmental conditions of the basin. The different meteorological parameters define a particular climate, which significantly modifies and alters the behavior of the drainage network and its environment. Therefore, it is important to know not only the annual and seasonal distribution of the different meteorological parameters, but also to analyze with special emphasis some of them, such as temperature and precipitation, given their direct impact on human activities in the basin. In this particular case, these are related to agricultural and livestock activities (Carbone et al., 2003).

In recent years, climate change is becoming evident in watersheds, where water availability is reduced causing severe droughts or excesses occur that can lead to flooding, exposing the economic, social and environmental activities that depend on it to greater risks. Knowledge of meteorological variables in the basin plays an important role for sustainable development and resilience on the part of decision makers to adapt to and mitigate the challenges of climate variability and climate change. Globally, this type of study has been carried out by several developing countries due to the challenges that climate variability and climate change impose on them. Barros et al. (2006) characterized the climate of the La Plata basin in South America in order to present in an orderly fashion the aspects of climate variability and change that influence surface water resources, especially the flows of the largest rivers in the basin. Carbone et al. (2003) characterized the Claromecó stream basin in Argentina climatically, with the aim of reducing the impacts of climatic adversities in order to determine the risk faced by agricultural and livestock activities.

In Cuba, work related to this topic has also been carried out by several researchers. Hernández and Fernández (2016) analyzed the climatology of the Cauto river basin in Cuba. The research was based on a detailed study of the climatic conditions of the region, with the objective of better understanding their influence on the hydrological cycle and water management in the area. They described the geographical and climatic characteristics of the Cauto River basin, highlighting its importance in terms of water resources and its vulnerability to climate changes. Pérez and Martínez (2017) hydroclimatically characterized the Zaza river basin in Cuba, stressing the importance of understanding the interaction between climate and water resources for sustainable water resource management. López and González in 2019 presented the importance of Cuban watersheds and their vulnerability to climate change, highlighting the need to understand and anticipate the impacts that this phenomenon may have on water availability and quality in the region. Salmo et al., (2023) in the province of Santiago de Cuba, characterized climatically the area of the San Juan river basin, with the objective of studying the behavior of temperature and precipitation variables, to create instruments that help to interpret the causes that provoke or aggravate vulnerabilities and allow the generation of prevention, mitigation and adaptation actions to face adverse phenomena and limiting economic-social development in the province.

In the Provincial Meteorological Center of Cienfuegos, this type of study has been carried out as part of services demanded by users, in addition to several projects and research theses associated with the province's watersheds. In the Cienfuegos territory, the development since 2015 of the master's program entitled "Integrated Management of Coastal Areas" proposed thesis topics related to watersheds, an example of this is the one developed by Eng. Natalia Mikulenko Borggiano who conducted a "Proposal of methodology for the Integrated Management of Hydrographic Basins (MICH). Case study: Arimao River Basin", characterizing climatically within her study said basin, also other masters in different editions of the program have dabbled in the subject.

The objective of this research is to characterize climatically the area of the Damují Hydrographic Basin in the province of Cienfuegos in order to raise the cognitive levels in the sustainable development of the agricultural sector of the province. This research is part of the results of the National Project: Strengthening the capacities of the agricultural sector of the province of Cienfuegos in mitigation and adaptation to Climate Change (AGROFORT_100).

2 Materials and methods

2.1 Study area

The province of Cienfuegos, located in south-central Cuba, between 21°50' and 22°30' north latitude and 80°06' and 80°55' west longitude, has four main streams: Salado, Arimao, Damují and Caonao. The Damují River is one of the four main streams, whose surface basin covers part of two territories, Cienfuegos and Villa Clara (Figure 1) and is located on the south-central slope of the island. Its main river, Damují, flows into the Bay of Cienfuegos. This basin has two important reservoirs, Salto and Abreus. Both reservoirs have socioeconomic importance in the province and their main uses are agriculture, fishing and industrial and human consumption.

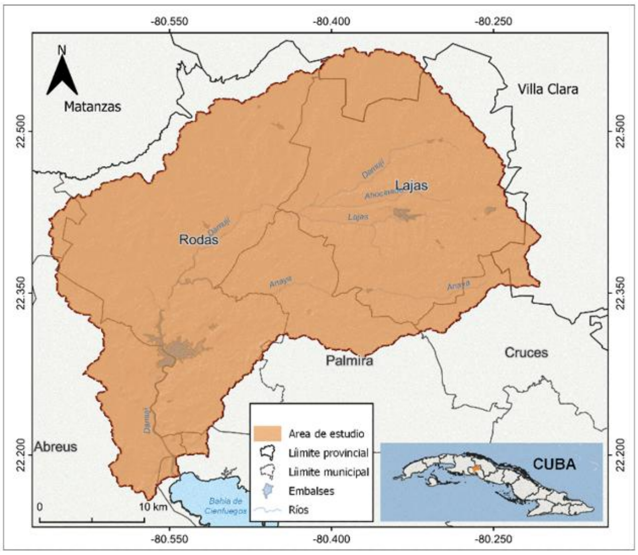

Figure 1. Location of the Damují basin

2.2 Methodology used

The preliminary results of the Agroclimatic Atlas of Cienfuegos Province (CMP, 2024 unpublished) were used to carry out this study, which contains the spatial distribution of the main meteorological variables, taking 1991-2020 as the standard climatic period. There was a digital database of all the meteorological variables of 62 meteorological stations belonging to the Network of the Institute of Meteorology (INSMET) which describe the behavior of the climate in all the physical-geographical zones of Cienfuegos province.

The spatial outputs of the Agroclimatic Atlas of Cienfuegos province are shown from a 4x4 km grid already used in other climatic and agrometeorological studies in the country (Figure 2), which was extended to the Damují basin areas belonging to Villa Clara province. A total of 73 points were considered for the entire basin. The following meteorological variables were calculated for each of these points:

• Average annual, monthly and seasonal temperature

• Average annual, monthly and seasonal minimum temperature

• Average annual, monthly and seasonal maximum temperature

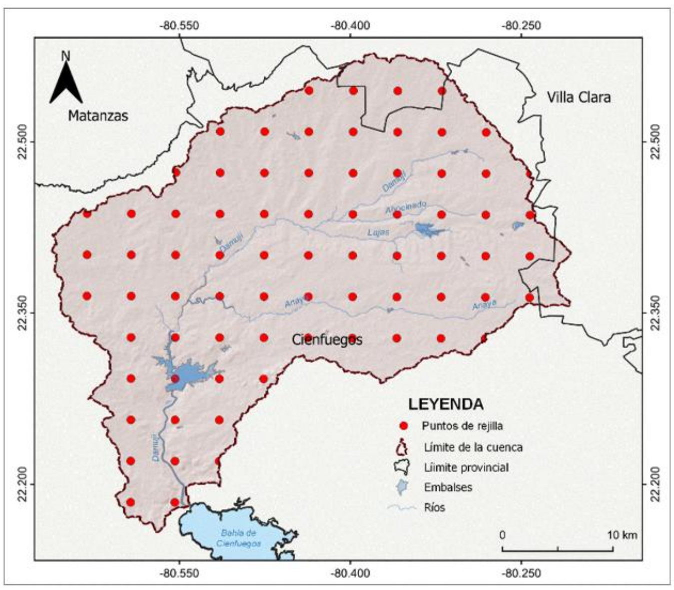

Figure 2. Grid points of the Damují basin

In the case of the analysis of precipitation in the area, the outputs of the National Meteorological Drought Monitoring System (SNVSM) of the National Climate Center of the Institute of Meteorology were used, also using the period 1991-2020 as the climate standard. The SNVSM is fed with pluviometric data from the basic network belonging to the National Institute of Hydraulic Resources and exports the data in the same 4 x 4 km grid mentioned above (Figure 2).

For the characterization of the wind in the area, data from 2 meteorological stations (Cienfuegos and Santo Domingo) for the period 1991-2020 were taken into account.

The analysis of dangerous meteorological phenomena and other phenomena that characterize the climate of the study area was based on the existing chronologies at the Cienfuegos Meteorological Center, which have been updated to date. In this case, the following were used:

•Tropical Cyclones that have affected Cienfuegos province (1971-2020)

• Cold fronts (1977-78 season to 2019-2020 season)

• Severe local storms (1971-2020)

The meteorological drought assessment was based on the calculation of the Standardized Precipitation Index (SPI). The SPI is an indicator based on the probability of rainfall in any period of time. It was developed in 1993 by McKee et al. (1993) to quantify the precipitation deficit over multiple time scales (1 month, 3, 6, 9 and up to 24 months). These time scales reflect the impact of drought on the availability of different water resources.

Technically, SPI is calculated by fitting the frequency distribution of precipitation at a given location, on the time scale of interest, with a theoretical probability density function. According to several authors (Thom, 1966; Young, 1992, Lloyd-Hughes, 2002, among others), the most appropriate function for this fit is Gamma. The density function is then transformed to a standardized normal distribution (with mean equal to 0 and variance equal to 1), with the SPI being the value resulting from this transformation. This index represents the number of standard deviations by which the transformed precipitation value deviates from the historical average (which is represented by 0). Negative values of the SPI represent precipitation deficit, and conversely, positive values indicate that the precipitation has been higher than the historical average. Table 1 shows the SPI classification.

Table 1. SPI classification (Edwards & McKee, 1997)

SPI Scale	Category	
≥2	Extreme	Excess
≥1.5<2	Severe	Excess
≥1<1.5	Moderate	Excess
≥0.5<1	Weak	
>-0.5<0.5	Normal	
≤-0.5>-1	Weak	Deficit
≤-1>-1.5	Moderate	Deficit
≤-1.5>-2	Severe	Deficit
<-2	Extreme	

The climatic regionalization of the area was made taking into account the Köppen-Geiger classification and Lang's pluviometric index.

According to the Köppen-Geiger classification, a climatic zone is of tropical (A) or temperate (C) type, when the mean monthly temperature of the coldest month is higher or lower than 18 °C, respectively. For type (A), if in a given region during all months of the year the accumulated precipitation is greater than 60 mm, it is classified as tropical rainforest (Af). If the minimum monthly precipitation is less than 60 mm, it is a dry season for which the following criteria of Kottek et al. (2006) and Peel et al. (2007) are applied:

$$rn < 100 - \frac{R}{25}\, Tipo\,(Aw) : \; Sabana\; Tropical \qquad \textbf{(1)}$$

$$rn > 100 - \frac{R}{25}\, Tipo\,(Am) : \; Monzónico \qquad \textbf{(2)}$$

For type (C), when the temperature of the warmest month is higher than 22 °C, it is classified as subtropical temperate; and if equations 3 and 4 are fulfilled, it means that the minimum precipitation occurs in winter (w) or summer (s), respectively. In all other cases, they are of type (f) (Kottek et al., 2006; Peel et al., 2007).

$$\frac{rn}{rx} > \frac{1}{3}\, Tipo\,(Cs) \qquad \textbf{(3)}$$

$$\frac{rn}{rx} > \frac{1}{10}\, Tipo\,(Cw) \qquad \textbf{(4)}$$

where:

R is the total annual precipitation, *rn* is the minimum monthly precipitation and *rx* is the maximum monthly precipitation.

The Lang index takes into account precipitation and mean annual temperature as fundamental climatic elements.

It is defined by the following formulation:

$$L = \frac{R}{Tm} \qquad \textbf{(5)}$$

where:

L is the Lang index, *R* is the total annual precipitation and *Tm* is the mean annual air temperature.

Although the Lang index originally has three categories: arid (less than 40 mm/ºC), humid (40 mm/ºC-160 mm/ºC) and super humid (greater than 160 mm/ºC). In order to achieve a better zoning of the study area, this work will use the divisions proposed by Álvarez (1992): very dry (less than 20 mm/ºC), dry (20 mm/ºC-40 mm/ºC), humid savanna (40 mm/ºC-60 mm/ºC), humid (60 mm/ºC-100 mm/ºC), very humid (100 mm/ºC-160 mm/ºC) and super humid (greater than 160 mm/ºC).

Finally, the trend of the basin's mean annual temperature and annual precipitation series was calculated for the period 1981-2020.

3 Results and discussion

The climate of the Damují basin, in correspondence with the climate of Cuba, is determined by its geographic position, which means that it receives the seasonal influence of tropical and extratropical atmospheric circulation zones. In the season that goes approximately from November to April, the variations of the weather and climate are associated fundamentally to the passage of frontal systems, to the anticyclonic influence of continental origin and of extratropical low pressure centers. From May to October, the more or less marked influence of the North Atlantic anticyclone predominates and the most important changes in the weather are linked to the presence of disturbances in the tropical circulation (easterly waves and tropical cyclones).

In addition, local conditions related to the physical-geographical factors of the study area give it very particular climatic characteristics that are evident mainly in the thermal and hydric regime of the territory. For example, the localities located in the northern part of the territory are characterized by a greater daily temperature oscillation, as well as a higher percentage of precipitation due to the convergence of sea breezes and land breezes. However, the areas near the bay stand out for having high temperatures and low rainfall accumulations due to the influence of sea breezes.

3.1 Cloudiness

Cloudiness in the basin is low throughout the year, with average values between 3 and 4 eighths of overcast. The highest values are reported from June to October, with a slight decrease during the rest of the year.

In general, the maximum cloudiness during the day is reached from 7:00 to 10:00 pm, while the minimum is recorded in the early morning.

3.2 Air temperature

In correspondence with the summer maximum of global solar radiation, the air temperature in the Damují basin reaches its annual maximum in July and August, while the annual minimum occurs in January and December. The annual march average air temperature shows that from May to October it exceeds 25 ºC on average. The minimum temperature also shows values above 20 ºC in this period and maximum temperatures above 30 ºC begin to occur in April and persist until October (Figure 3).

The mean annual temperature in the Damují basin does not vary greatly spatially. There is a predominance of values between 24-25ºC in most of its surface, increasing slightly in the southern portion with records between 25-26ºC (Figure 4).

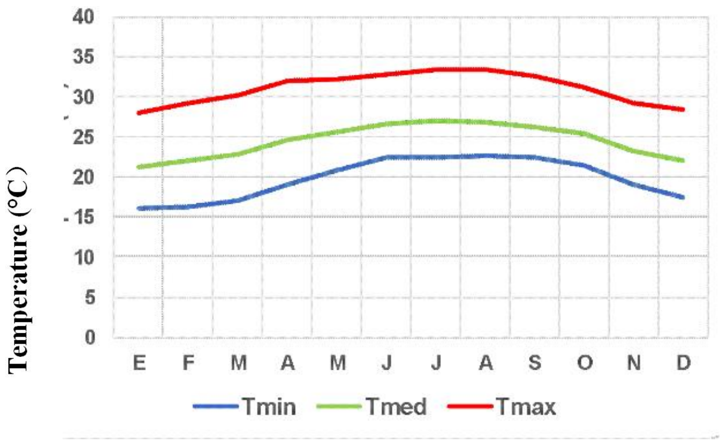

Figure 3. Annual air temperature trend in the Damují basin. Period 1991-2020

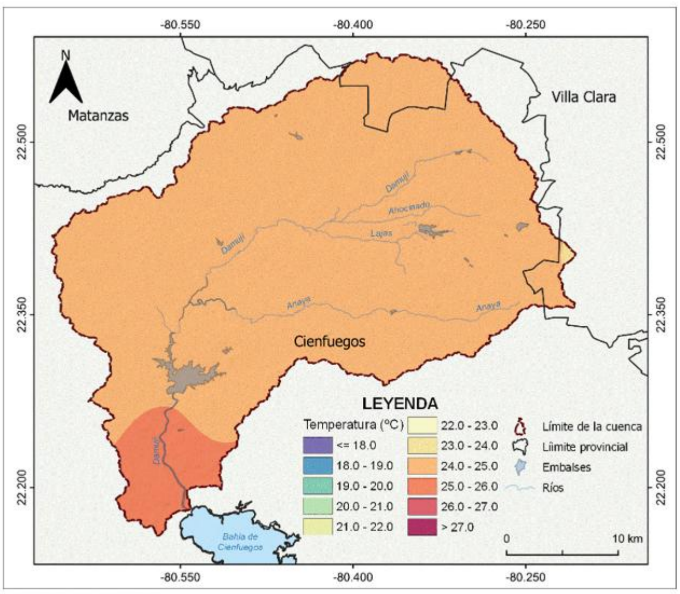

Figure 4. Average temperature in the Damují basin. Period 1991-2020.

This distribution is somewhat similar depending on the months of the year. It can be seen that in July, one of the warmest months of the year, the average temperature in the center-south of the basin reaches values above 27ºC, while in the northern half it ranges between 26-27ºC (Figure 5-right). On the other hand, in January, the coldest month of the year, the lowest temperatures are recorded towards the northern end of the basin and increase slightly towards the center-south with values that can exceed 22ºC (Figure 5-left).

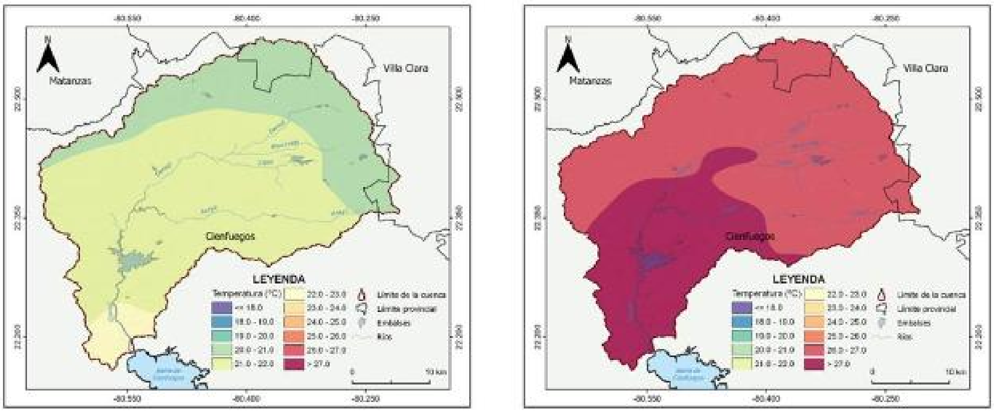

Figure 5. Average temperature in the months of January (left) and July (right) in the Damují basin. Period 1991-2020.

Figure 6 shows the spatial behavior of extreme temperatures in the Damují basin. The lowest average minimum temperature values occur towards the north of the basin, while the lowest average maximum temperature values are recorded in the southern areas of the basin. This is due to the thermoregulatory effect of the proximity to the sea in the southern areas of the basin, which means that temperatures do not drop much during the early morning and do not increase extremely during the hours of greatest diurnal warming. This is why in this area of the basin the thermal oscillation is lower than in the northern half of the basin.

In the northern half of the study area, maximum temperatures can exceed 31.0 ºC as an annual average; however, in the months of July and August they can exceed 33.5 ºC as an average. In the case of minimum temperatures, the northernmost part of the basin can experience significant values, which in December, January and February can average below 16ºC. The occurrence of significant minimum temperatures is a particularity of this zone, where surface cooling processes are more intense due to nocturnal heat irradiation on clear, windless days (Lecha et al., 1994).

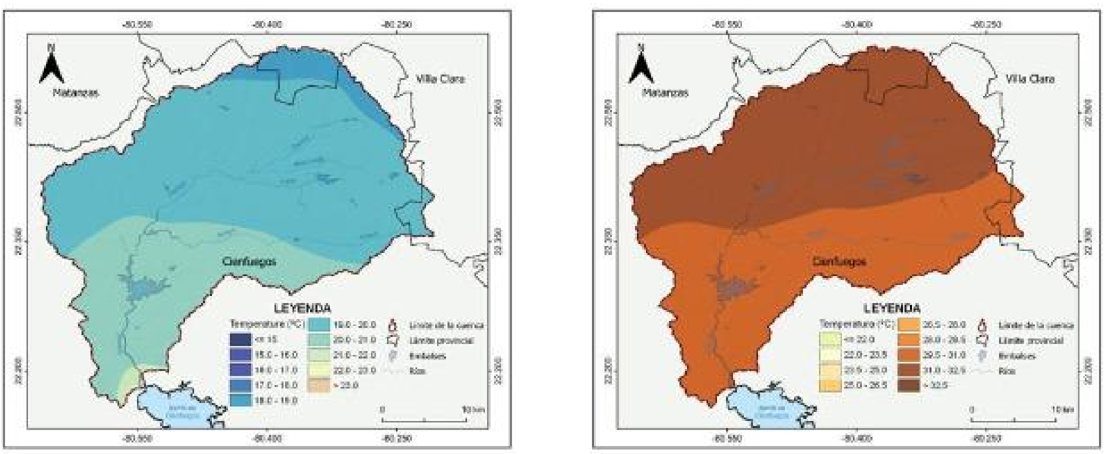

Figure 6. Average annual minimum temperature (left) and average annual maximum temperature (right) in the Damují basin. Period 1991-2020

3.3 Precipitation

In the Damují basin, the average annual accumulated rainfall reaches a total of 1422.1 mm. In its annual course, there is a marked seasonality, with a rainy period from May to October, when 82.2% of the total annual rainfall accumulates, and another rainy period from November to April, when the remaining 17.8% accumulates.

In July and August there is a relative decrease in rainfall, known as "intra-summer drought". The driest months are December (30.1 mm), January (33.3 mm) and February (32.2 mm) and the wettest months are June (214.6 mm) and September (219 mm) (Figure 7).

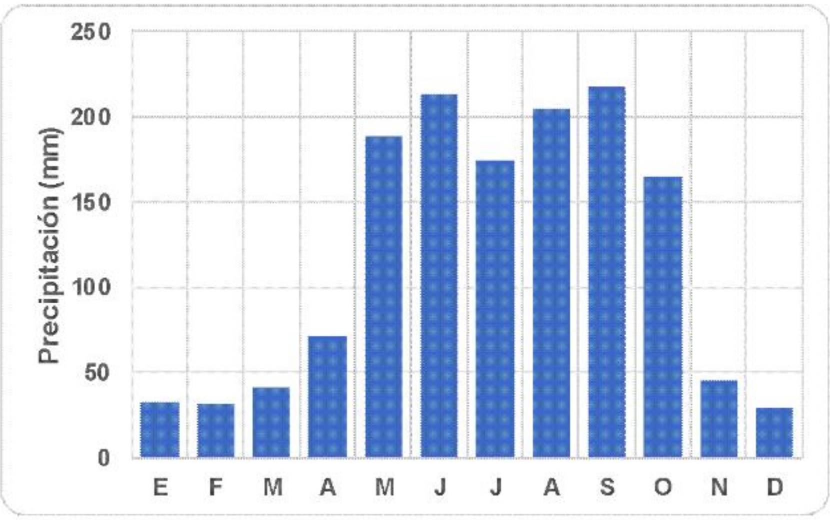

Figure 7. Annual rainfall accumulated in the basin. Standard 1991-2020.

Annual rainfall in the basin peaks towards the southern center with values above 1400 mm, coinciding with the convergence zone of the breezes where precipitation values are higher. Towards the north there is a gradual decrease with average values between 1300-1350 mm (Figure 8).

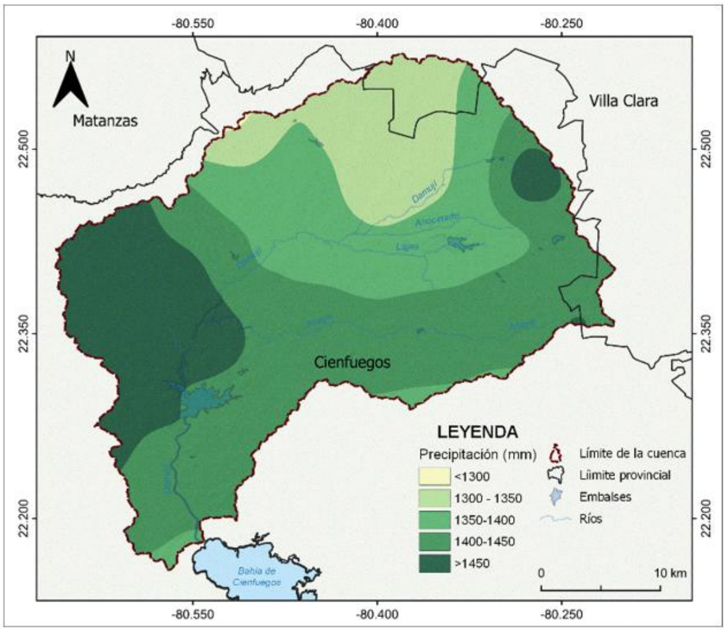

Figure 8. Annual rainfall in the Damují basin. Period 1991-2020.

The spatial distribution of precipitation in the rainy period of the year shows a similar configuration to the previous one. In this case, values between 1150-1200 mm predominate in most of the basin; however, there is an area to the west of the basin with records above 1200 mm (Figure 9-left). The map of the spatial distribution of rainfall in the low rainfall season shows that rainfall is scarce throughout the basin, with the lowest accumulations (<250 mm) in the northern half of the basin (Figure 9-right).

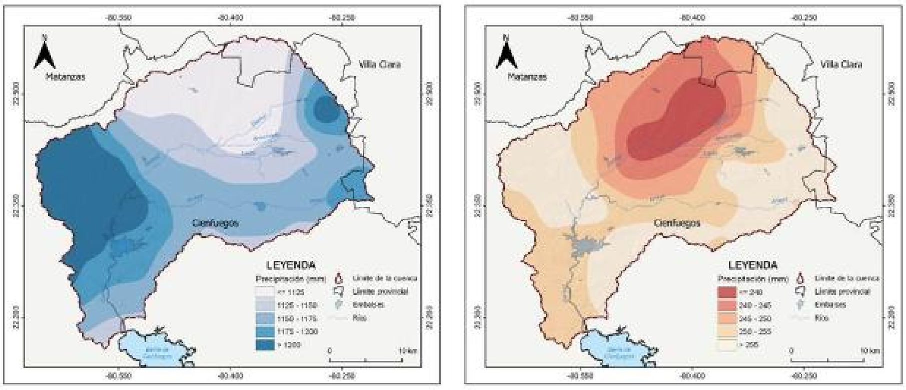

Figure 9. Rainfall in the rainy period (left) and low rainfall period (right) in the Damují basin. Period 1991-2020

This basin is characterized by a more uniform wetting regime throughout the year. This is demonstrated by the relative proportion of rainfall in the rainy period with respect to the annual accumulated rainfall (Figure 10). It can be seen that in most of the basin this proportion reaches 82-84%, with lower ranges towards the interior of the study area.

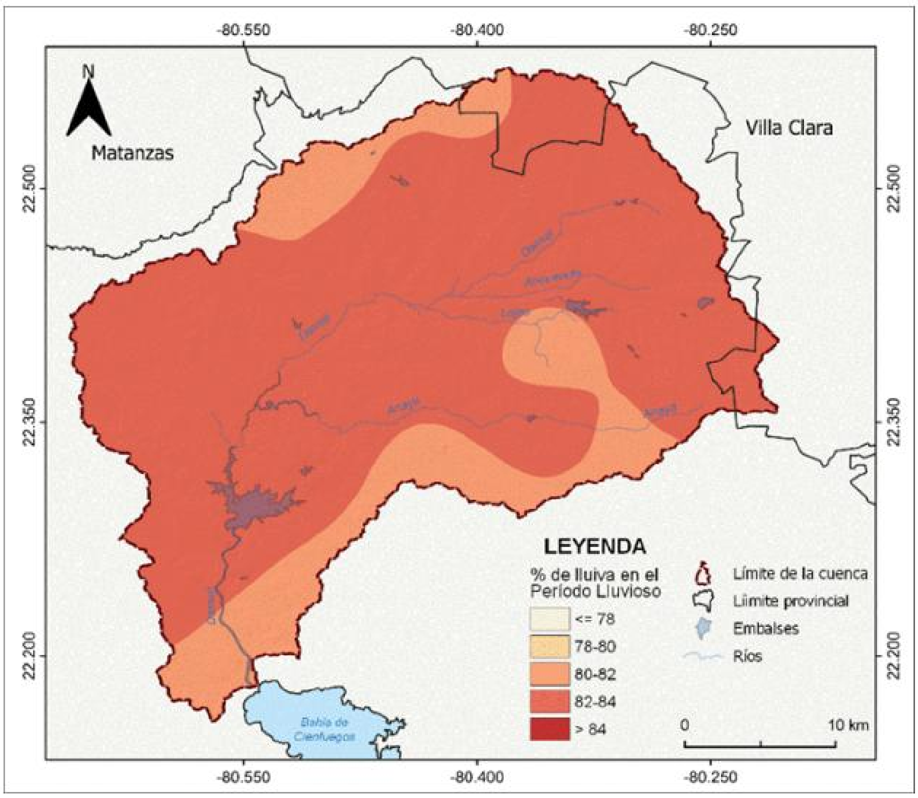

Figure 10. Relative proportion of precipitation occurring in the rainy period with respect to the annual total. Damují basin. Standard 1991-2020.

3.4 Relative humidity

Relative air humidity is an important climatic element that, in combination with temperature, plays a relevant role in weathering. The atmospheric circulation conditions, the distribution of precipitation, the relief of the territory and the marine influence are the main factors that intervene in its characteristics. In general, the basin is dominated by annual average values of around 78%, with the lowest values of spatial distribution in the area near the bay, which range between 74-76% as an annual average.

Its annual trend corresponds to the seasonal distribution of rainfall, with peaks in September and October and troughs at the end of the low rainfall period of the year in March and April.

3.5 Winds

Winds in Cuba do not usually have very high speeds, on average. The maximum values occur during the day, usually in the early afternoon; the minimums are observed at night and in the early morning. Their behavior has a very local character and they are governed to a great extent by the orographic effect.

In the study area, winds predominate from the northeast to the east, as shown in Figure 11. Towards the south of the basin the predominant wind is from the northeast, while towards the highest part and to the north the most predominant component is from the east.

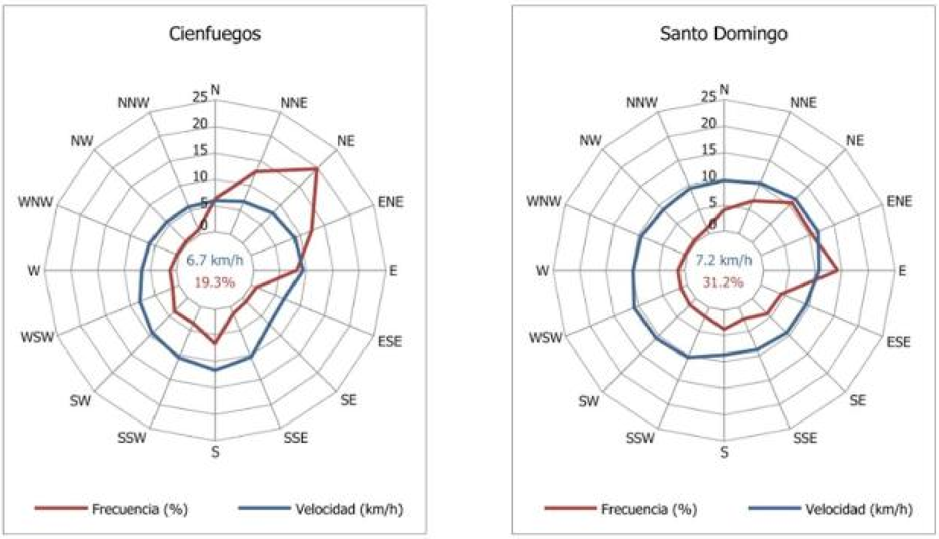

Figure 11. Annual wind rose at selected meteorological stations. Period 1991-2020.

In the area of the basin near the coast, local winds such as breezes and terral are present. Sea breezes begin to appear from late morning until the afternoon, in this case they present components from the south to the southwest (Figure 12).

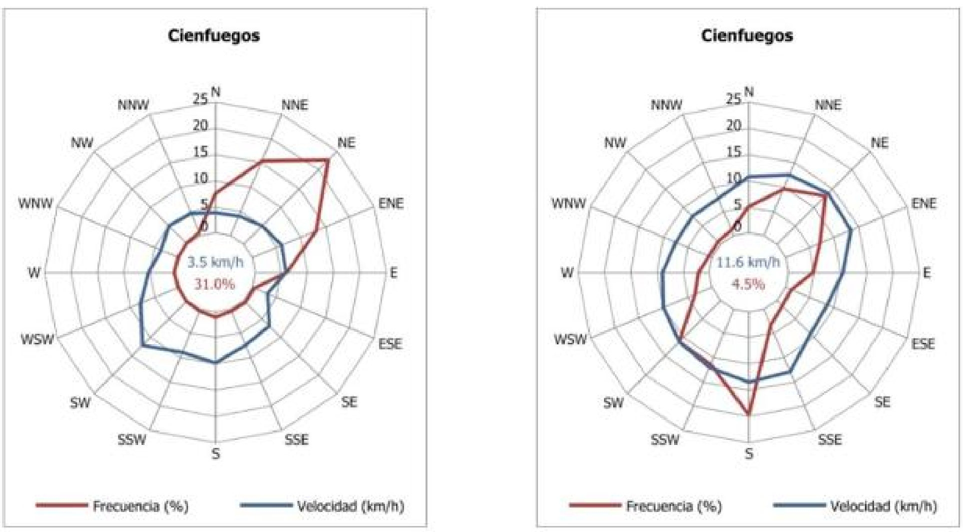

Figure 12. Wind rose at 4:00 am (left) and 4:00 pm (right) at the Cienfuegos weather station. Period 1991-2020.

The annual wind speed trend shows its highest values in the months of the low rainfall period (Table 2), while the lowest values are recorded in the August-September two-month period. In general, maximum wind speeds are associated with frontal systems, extratropical low pressure centers, local storms, cyclonic disturbances and hurricanes.

Table 2. Average monthly wind speed (km/h) by selected stations for the period 1991-2020

Stations	E	F	M	A	M	J	J	A	S	O	N	D	Annual
Cienfuegos	7.9	8	8.9	8.4	6.8	5.4	5.1	4.8	4.6	5.6	7.2	7.4	6.7
Santo Domingo	7.6	7.9	8.9	8.6	7.5	5.9	6.4	5.7	5.3	6.8	8.0	7.4	7.2

3.6 Hazardous weather and climate phenomena

3.6.1 Strong winds

Maximum wind speeds in Cuba occur during the passage of migratory continental anticyclones, cold fronts, extratropical cyclones, severe local storms, hurricanes, among other phenomena. In the case of the Damují basin, the occurrence of these phenomena is mainly associated with tropical cyclones and the occurrence of severe local storms, phenomena that will be analyzed later on.

3.6.2 Heavy rains

Intense rainfall (accumulated in 24 hours ≥ 100 mm) in the basin is most frequent during the rainy period of the year, specifically in the months of May, June and October, followed by September and August. The genesis of this type of severe precipitation in the area is mainly associated with the characteristic depressions of the months of May and June and tropical cyclones.

Among the most significant intense rainfall events in the territory were the numerous rains that occurred between May 31 and June 1, 1988. The meteorological situation that led to this event was due to a complex process associated with the connection between a weak tropical depression in the northwestern Caribbean and a deep short wave in the west, which encouraged the development of an intense band of convective clouds. In the basin, accumulations of over 100 mm were reported during these two days, exceeding 200 mm in several points.

The intense rainfall event caused by the influence of subtropical storm Alberto on May 25, 26 and 27, 2018, was undoubtedly the most extreme to affect the basin in the last 20 years. During those days, accumulated rainfall in excess of 400 mm was reported in several areas, which caused flooding in low-lying areas.

In July 2005, there were also significant heavy rains associated with Hurricane Dennis that affected the province on the 8th and 9th. On the 8th, accumulated rainfall of more than 200 mm was reported at several points in the basin.

In the month of October, most of the extreme precipitation events have been associated with tropical cyclones, as previously mentioned. The rains related to Tropical Storm Irene in 1999 and Hurricane Lili in 1996 stand out.

3.6.3 Tropical cyclones

The cyclonic season in the North Atlantic lasts from June 1 to November 30, reaching its highest intensity at the end of August and in September (Landsea, 2007). Statistically, the peak of activity of the hurricane season in the Atlantic is September 10. In the case of Cuba, the highest frequency of hurricane activity occurs in October, followed by September and August. Most of the hurricanes affecting Cuba originate in the Caribbean Sea, while the rest originate in the Atlantic Ocean.

In the 1971-2020 period, the following TCs stand out as those that have affected the Damují basin either by the occurrence of strong winds or heavy rains (in bold those that have transited within the boundaries of the Cienfuegos province (Figure 13):

• Tropical Storm Frederic, September 1979, affected by heavy rains.

• Tropical Storm Dennis, August 1981, affected by heavy rains.

• Hurricane Kate, November 1985, affected by heavy rains and strong winds.

• Hurricane Floyd, October 1987, affected by heavy rainfall.

• Tropical Storm Gordon, November 1994, affected by heavy rains.

• Hurricane Lili, October 1996, Category 2 (SS), affected by strong winds, heavy rains.

• Hurricane Georges, September 1998, affected by heavy rains.

• Hurricane Irene, October 1999, affected by heavy rains and strong winds.

• Hurricane Michelle, November 2001, Category 3 (SS), affected by strong winds, heavy rains.

• Hurricane Isidore, September 2002, affected by heavy rains.

• Hurricane Dennis, July 2005, Category 3 (SS), affected by strong winds, heavy rains.

• Hurricane Rita, September 2005, affected by heavy rains.

• Tropical Storm Fay, August 2008, heavy rainfall damage.

• Hurricane Gustav, August 2008, affected by heavy rains.

• Hurricane Ike, September 2008, affected by heavy rains and strong winds.

• Tropical Storm Nicole, September 2010, heavy rainfall damage.

• Tropical Storm Isaac, August 2012, affected by heavy rains.

• Hurricane Sandy, October 2012, affected by heavy rains.

• Hurricane Irma, September 2017, affected by heavy rains and strong winds.

• Subtropical storm Alberto, May 2018, affected by heavy rains.

• Tropical Storm Laura, August 2020, affected by heavy rains.

• Tropical Storm Eta, November 2020, affected by heavy rains.

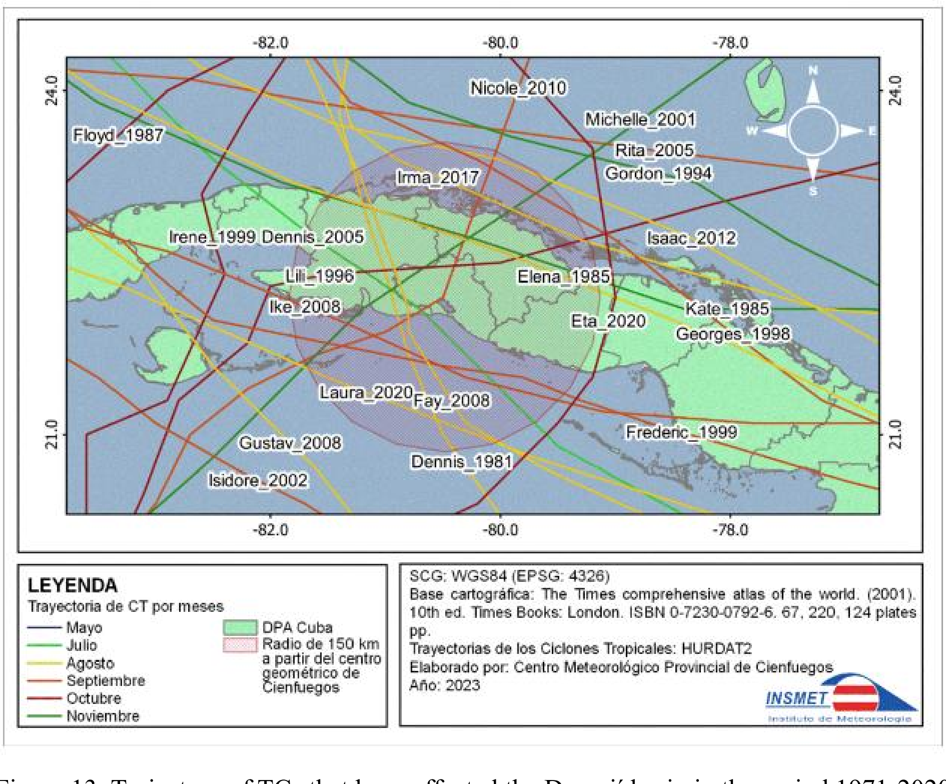

Figure 13. Trajectory of TCs that have affected the Damují basin in the period 1971-2020

3.6.4 Lightning storms

The annual behavior indicates that the months with the highest number of days with storms are July and August with more than 20 days, followed by September and June. On the other hand, the months in which storms occur less frequently are the coldest months of the year: December, January and February. This behavior is largely due to the fact that in the summer months the air mass that predominates over the national territory is more humid and unstable, which favors the formation of convective cloudiness, while in the winter period the imposition of migratory anticyclones with drier, more stable air masses and stronger pressure gradients do not favor these processes; although it is not ruled out that storms associated with cold fronts and prefrontal lines may occur during this period of the year.

3.6.5 Severe local storms (SLS)

According to the chronology available to the CMPCF, the Damují basin is located in the area of the province with the highest frequency of SLS occurrence. The greatest reports are of tornadoes **(Note 1)**, turbulence and hailstorms. May and June are the months with the highest frequency of occurrence.

3.6.6 Meteorological drought

Drought is a meteorological phenomenon that affects water resources, affecting the availability of water in the years in which it occurs. The World Meteorological Organization (WMO) defines it as: "a period of abnormally dry weather conditions and sufficiently prolonged, so that the lack of precipitation causes a serious hydrological imbalance".

The SPI analysis, for the hydrological years of the 1961 - 2020 series, showed the presence of drought for the entire basin area in certain periods and made it possible to characterize them in terms of their intensity. Table 3 highlights the severity of the drought event that extended from 1961 to 1966, with its most significant extremes in the first three years. This stands out as the most significant meteorological drought event in the period evaluated.

In the study period, 12 hydrological years with meteorological drought from moderate to extreme stand out, with the years 1961-1962 and 2004-2005 as the most significant with rainfall deficits classified as extreme. They are followed in order of importance by the years 1962-1963, 1967-1968, 1970-1971 and 2019-2020 with SPI values below -1.2, which represents an accumulated less than 80% of the annual mean (Figure 14 and Table 3).

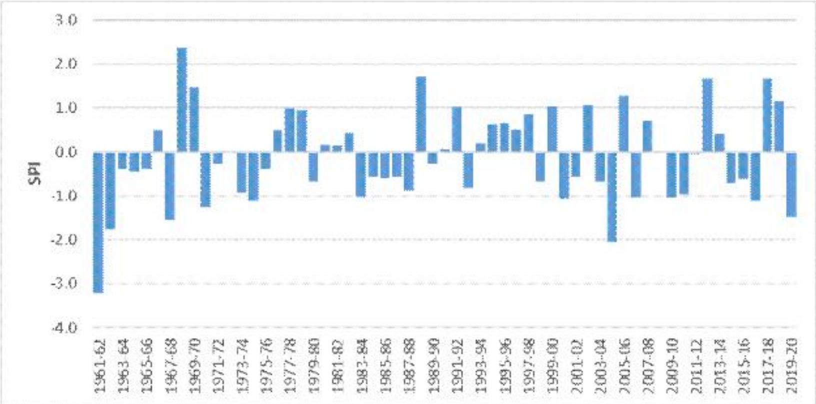

Figure 14. SPI values in the time series corresponding to the hydrological years of the period 1961-2020. Standard 1991-2020.

Table 3. Annual standardized precipitation index (SPI), for water years 1961-1962 through 2019-2020. Standard 1991-2020

Hydrological Year	SPI	Classification	Hydrological Year	SPI	Classification
1961-62	-3.2	Extremely Dry	1991-92	1.0	Weakly Humid
1962-63	-1.8	Severely Dry	1992-93	-0.8	Moderately Dry
1963-64	-0.4	Normal	1993-94	0.2	Normal
1964-65	-0.5	Normal	1994-95	0.6	Normal
1965-66	-0.4	Normal	1995-96	0.7	Weakly Humid
1966-67	0.5	Normal	1996-97	0.5	Normal
1967-68	-1.6	Severely Dry	1997-98	0.9	Weakly Humid
1968-69	2.4	Extremely Humid	1998-99	-0.7	Weakly Dry
1969-70	1.5	Severely Humid	1999-00	1.0	Weakly Humid
1970-71	-1.3	Moderately Dry	2000-01	-1.1	Moderately dry
1971-72	-0.3	Normal	2001-02	-0.6	Weakly Dry
1972-73	0.0	Normal	2002-03	1.1	Weakly Humid
1973-74	-0.9	Weakly Dry	2003-04	-0.7	Weakly Dry
1974-75	-1.1	Moderately Dry	2004-05	-2.1	Extremely Dry
1975-76	-0.4	Normal	2005-06	1.3	Moderately Humid
1976-77	0.5	Normal	2006-07	-1.0	Weakly Dry
1977-78	1.0	Weakly Humid	2007-08	0.7	Weakly Humid
1978-79	0.9	Weakly Humid	2008-09	0.0	Normal
1979-80	-0.7	Weakly Dry	2009-10	-1.0	Weakly Dry
1980-81	0.2	Normal	2010-11	-1.0	Weakly Dry
1981-82	0.1	Normal	2011-12	0.0	Normal
1982-83	0.4	Normal	2012-13	1.7	Severely Humid
1983-84	-1.0	Weakly Dry	2013-14	0.4	Normal
1984-85	-0.6	Weakly Dry	2014-15	-0.7	Weakly Dry
1985-86	-0.6	Weakly Dry	2015-16	-0.6	Weakly Dry
1986-87	-0.6	Weakly Dry	2016-17	-1.1	Moderately Dry
1987-88	-0.9	Weakly Dry	2017-18	1.7	Severely Humid
1988-89	1.7	Severely Wet	2018-19	1.2	Moderately Humid
1989-90	-0.3	Normal	2019-20	-1.5	Moderately Dry
1990-91	0.1	Normal			

As can be seen in the present century, the presence of 3 very dry hydrological years (2000-2001, 2004-2005, 2016-2017 and 2019-2020) stand out, some of them associated with the most important meteorological drought events that have affected the country since 2000 (Table 3 and Figure 15).

Likewise, 8 years from moderately wet to extremely wet were recorded in this period, highlighting the hydrological years 1968-1969, 1969-1970, 1988-1989, 2012-2013 and 2017-2018 as the most significant (Table 3).

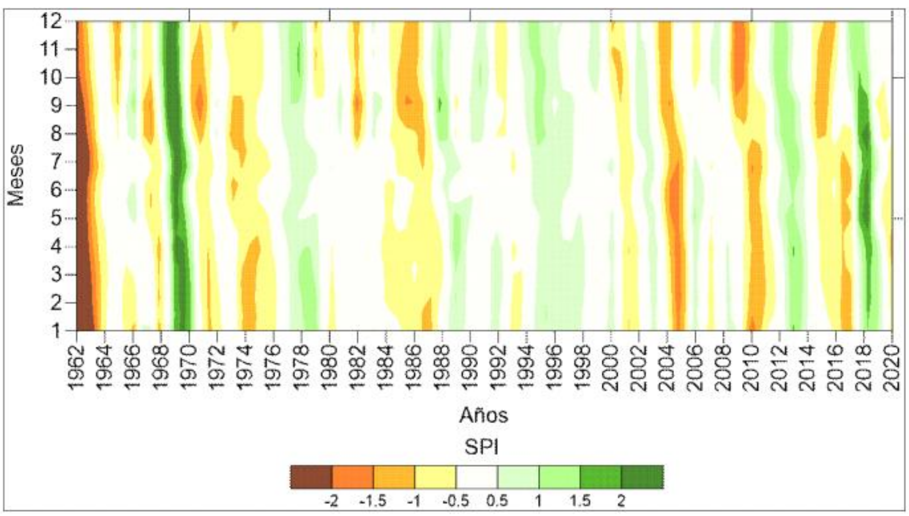

Figure 15. SPI 12 characteristic chart of the Damují basin. Period 1961-2020. Standard 1991-2020.

Figure 16 shows the seasonal behavior of the SPI for each seasonal period, an indicator of how far from the expected values the rainfall reports behaved during the period analyzed. It can be seen that since 2000 there has been a tendency to have low rainfall seasonal periods with below-normal accumulations and moderate to extreme deficits.

Figure 16. SPI values in the time series corresponding to the rainy period (left) and dry period (right) in the period 1961-2020. Standard 1991-2020.

3.6.7 Cold fronts

The behavior of frontal systems over Cuba is due to their displacement from West to East, losing in this movement the associated meteorological characteristics that they had at the beginning of their journey, in the fields corresponding to wind, temperature and humidity, among others. This loss of identity of the frontal systems is due to transformations that the air masses undergo as they move over tropical latitudes; that is why not all Cuban provinces are exposed to the same rigor of affectation or with the same intensity, González (1999). In the case of Cienfuegos, in the period 1977-2020, which corresponds to 46 winter seasons of cold fronts (FF) that affected the country, 653 cold fronts reached the province with an annual average of 15.5 FF (Figure 17).

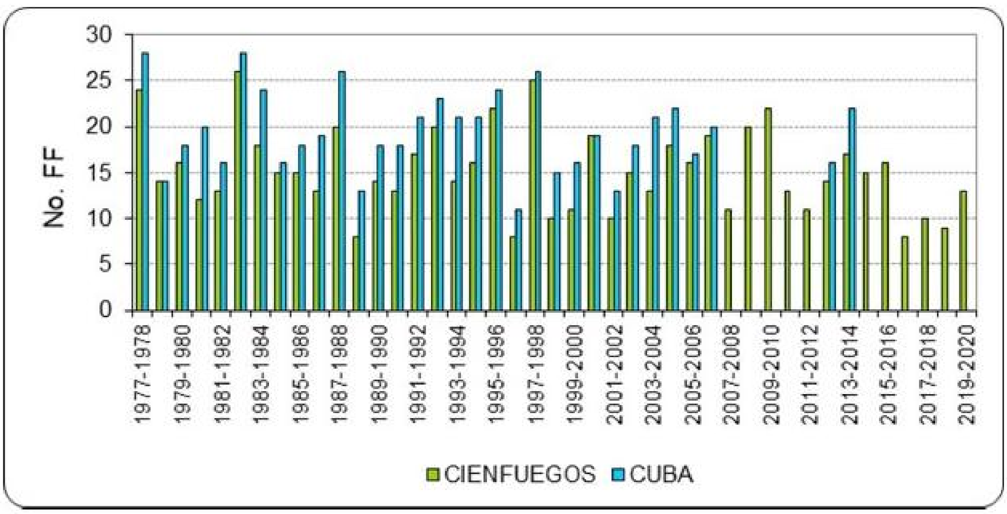

Figure 17. Number of cold fronts that have affected Cuba and the province of Cienfuegos from the 1977-78 season to the 2019-20 season.

The interannual variability is wide, ranging from 6 to 26 systems. The most affected period includes the months of December through March with averages ranging between 2 and 3 monthly fronts. These fronts are responsible for a large part of the precipitation reported during the low rainfall period.

The most active seasons recognized in this chronology are those of 1982-1983 with 26 frontal systems, followed by 1997-1998 and 1977-1978 with 25 and 24 fronts, respectively. It is worth noting that all these seasons coincide with El

Niño-Southern Oscillation (ENSO) events, demonstrating the relationship between the frequency of cold fronts affecting the country and the ENSO event.

3.6.8 Climate regionalization

The climatic regionalization of a given area presupposes the grouping of territories on the basis of the characteristics of one or more of the climatic elements that constitute the local climate of a region. Temperature and precipitation regimes are the climatic elements that most effectively characterize a region's climate, while the spatiotemporal distribution has practical and scientific value in decision-making by different socioeconomic sectors.

According to Lang's classification and taking into account the 1991-2020 Climate Standard, the basin has two categories: humid savanna and humid (Figure 18).

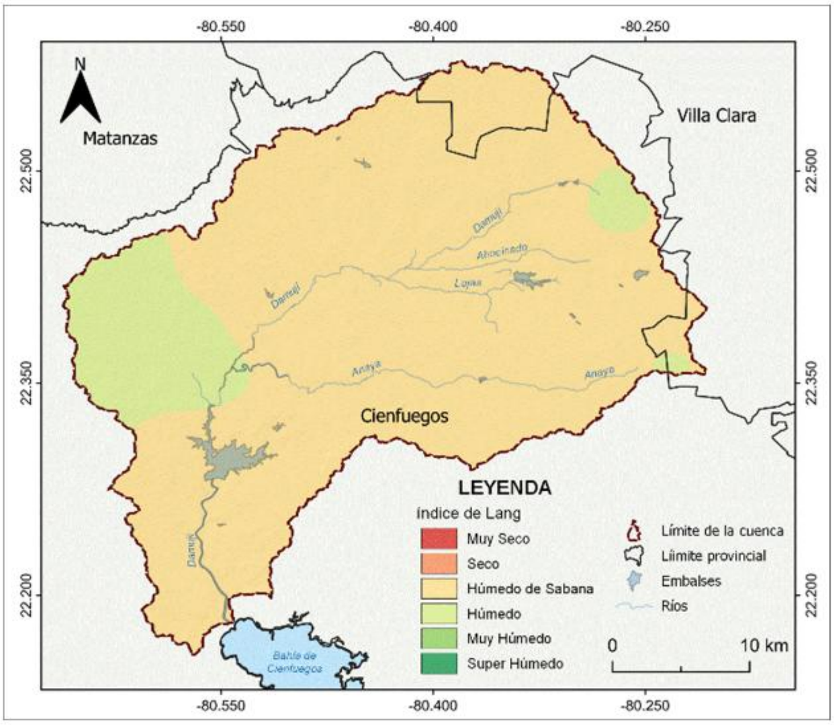

Figure 18. Climate regionalization using the Lang index for the Damují basin according to the 1991-2020 climate standard.

In addition to the above classification, the Köppen-Geiger classification was used, which, based on the configuration of the relief in combination with local conditions, makes it possible to distinguish a single type of climate (Aw) in the basin. The tropical savanna climate (Aw) is characterized by an average temperature of more than 18 ºC in the coldest month and a dry season in winter.

3.7 Trend of some climatic variables

3.7.1 Average temperature

The behavior of the mean annual temperature in the study area reflects the increase experienced globally and nationally. Since 1981 to date, there has been a sustained and significant increase in this meteorological variable, which has meant that after 2012 the mean annual value in the basin has remained permanently above 24.5 ºC, even above 25 ºC in the last two years of the series (Figure 19).

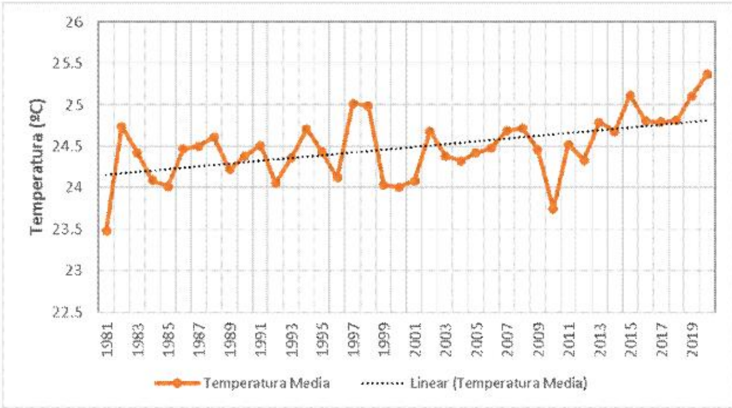

Figure 19. Average temperature trend in the Damují basin for the period 1981-2020.

The spatial distribution of this variable in the study area from 1981 to 2020 also shows this increase, which has been more significant towards the south of the basin (Figure 20).

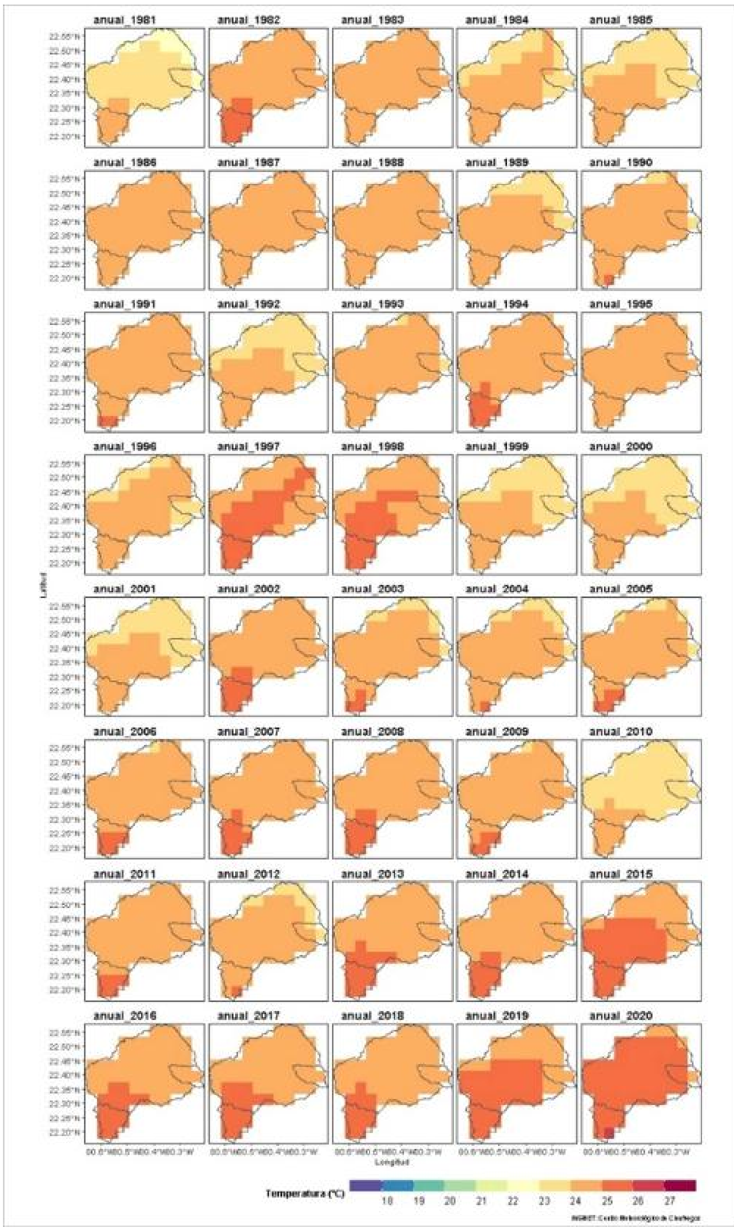

Figure 20. Distribution of mean annual temperature in the Damují basin for the period 1981-2020.

3.7.2 Rain trend

The series of annual precipitation values for the Damují basin does not show a statistically significant trend (Figure 21). The analysis by seasonal periods (low rainfall and rainy) shows that there are no significant trends in the province either. However, it can be seen that in all three cases the slope is positive.

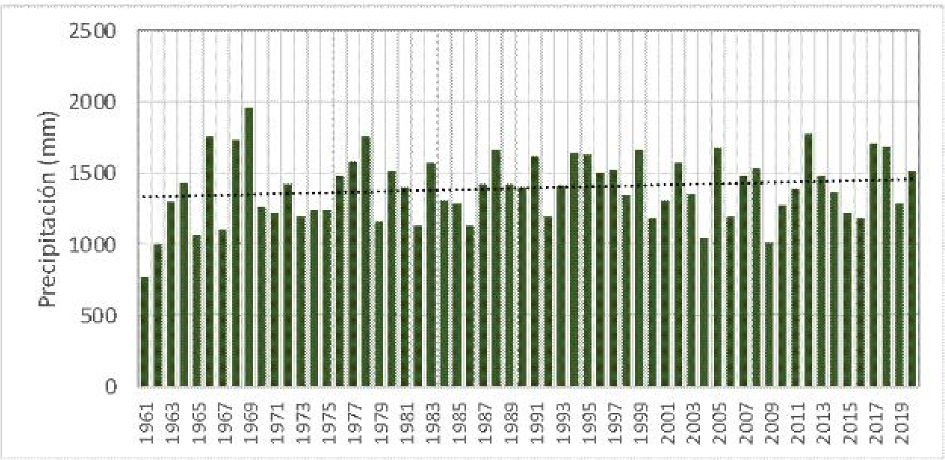

Figure 21. Annual rainfall behavior in the Damují watershed. Period 1961-2020.

A simple inspection of the graphs in Figures 22 shows that in the case of the low rainfall period since 2000, there is a marked tendency to record accumulations below historical values in the basin, which was already evident in the analysis of the meteorological drought.

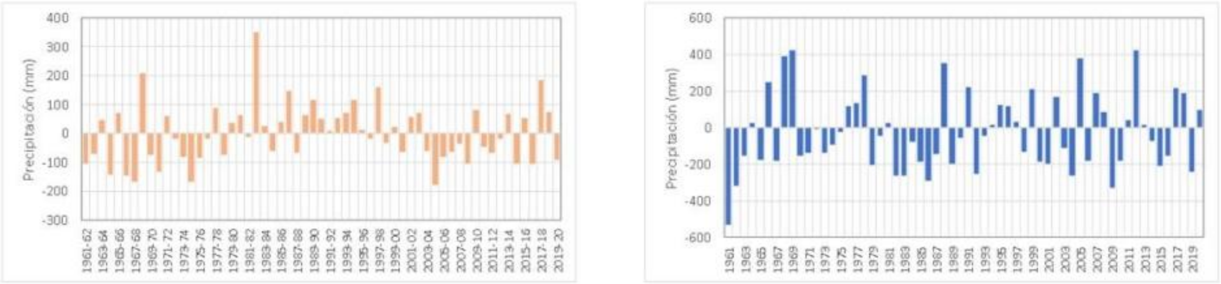

Figure 22. Rainfall anomalies in the Low Rainfall Period (Left) and Rainy Period (Right) of the year in the Damují basin. Period 1961-2020.

4 Conclusion

• The average annual temperature of the Damují watershed does not experience significant spatial variation, with values ranging between 24 and 25°C across most of its surface, increasing slightly in the southern portion with records between 25 and 26°C.

• In the Damují watershed, the average annual rainfall totals 1,422.1 mm.

• Relative humidity predominates, with average annual values around 78%.

• The watershed has two climatic regions: humid savanna and humid.

• Knowledge of the meteorological variables in the watershed plays an important role in sustainable development and resilience for decision-makers to adapt to and mitigate the challenges of climate variability and climate change.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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Notes

1. Turbonade: linear wind gusts of 96 km/h (26.6 m/s) or more, not directly associated with a tornado, Manual of Procedure (2000).

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