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CLIMATOLOGICAL WATER BALANCE IN NORTH FLUMINESE (PERIOD FROM JANUARY/2012 TO NOVEMBER/2023): A CASE STUDY

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Abstract: As the climate is the factor that most influences sugarcane productivity and aware of the lack of information about the culture's production environment and the financial impact that the sugarcane sector provides in the North Fluminense Region, RJ were the motivators for the realization of this study on the normal and sequential climatological water balance during the months of January/2012 to November/2023. In summary, it was concluded that the analysis of the normal climatological water balance showed a change in the rainfall regime in Campos dos Goytacazes, RJ, with a water deficit in almost all months of the year, indicating the need for readjustment in the region's agricultural planning. The analysis of the sequential climatological water balance indicated water deficiency in almost all 429 evaluated ten-year periods (12 years) and only 47 ten-year periods with a water surplus, the majority of which, from the year 2020 onwards, were justified by the increase in high rainfall events. intensity, indicating the need for changes in decision-making in the regional agricultural sector. Finally, it can be concluded that the water deficit is high in all months of the year and that the rainfall regime is inefficient to overcome it.

Keywords: Irrigation, evapotranspiration, water in the soil, agrometeorology, climate change

INTRODUCTION

The North Fluminense region has as one of its main economic activities the sugar and alcohol industry, having generated in the year 2000 around 175 million reais and around 15,000 direct and indirect jobs. This activity, however, in the last four decades has been going through a process of decline due to successive economic plans, devaluation of the national currency in relation to the dollar, financial debt assumed by production units in the modernization of industries, strong competitive pressures imposed by the market that it requires productivity and quality at increasingly lower costs, and a lack of raw material (sugarcane) due to the water deficit characteristic of the region (Azevedo et al., 2002).

According to the National Supply Company - CONAB (2023), the State of Rio de Janeiro is the 11th producer of sugar cane in Brazil, with estimated production in the 2022/23 harvest in an area of 35.5 thousand hectares, 1,579 2 thousand tons of the product, with the municipality of Campos dos Goytacazes, located in the north of Rio de Janeiro, being the largest producer of sugar cane in the State. The same survey predicts for the 2023/24 harvest a 12% reduction in production (1,389.1 thousand tons) and a 16.1% reduction in the planted area (29.8 thousand hectares).

The lack of information about the sugarcane production environment and the financial impact that the sugarcane sector provides in this production region motivated this study on the sequential climatological water balance during the last 12 harvest years.

Climate is the factor that most influences sugarcane productivity (Ide and Oliveira, 1986; Barbieri, 1993). In Brazil, due to its large territorial extension, there are the most varied climatic conditions for the development of sugarcane farming. Certain regions have an ideal climate, without any restrictions, while others have moderate thermal and/or water restrictions, which allow economic production of the crop without requiring special resources and techniques. However, there are those where there are limiting restrictions and only the cultivation of selected varieties and the use of extra resources they can correct water deficiencies, making sugarcane farming economically viable.

Some authors define temperature as the most important factor for the physiological maturation of sugarcane, because, in addition to affecting the absorption of water and nutrients through transpiration flow, it is a non-controllable condition (Ometto, 1980; Ide and Banchi, 1984; Ide and Oliveira, 1986; Magalhães, 1987; Barbieri, 1993). Sugar cane grows well in regions with a hot climate. Temperatures ranging between 26°C and 33°C are favorable during the crop development stage. Temperatures below 21°C are favorable during the maturation stage, as they reduce the rate of culm elongation and promote the accumulation of sucrose (Magalhães, 1987).

Soil moisture is another preponderant factor and varies depending on the type of soil, the crop cycle (sugarcane or ratoon), the stage of development (phenological cycle), climatic conditions and other factors, such as water available in the soil. and cultivated varieties.

The distribution of precipitation during the year is the most important factor for the development of the crop, as there may be water shortages at different stages, resulting in decreases in productivity.

For studies of water loss to the atmosphere in vegetated soils and the behavior of various meteorological elements, it is essential to know the soil water balance and its variations, requiring measurements of rainfall and evapotranspiration, in addition to knowing the components soil physics (Vianello and Alves, 1991).

According to Sentelhas et al. (1999), the Climatological Water Balance (BHC) was initially developed with the aim of characterizing the climate of a region, in order to be used in the climate classification developed by Thornthwaite in the 1940s. Later, this method began to be used to agronomic purposes given to the great interrelationship between agriculture and climatic conditions. The BHC prepared with average data on rainfall (P) and potential evapotranspiration (ETP or ETo) for a given region is called Normal BHC, this type of balance being water an indicator of water availability in a given region, through the seasonal variation of BH conditions over an average (cyclical) year, that is, periods with water deficiencies and surpluses. This information is of a climatic nature and, therefore, helps in agricultural planning. The BHC prepared with P and ETP data from a period or a sequence of periods (months, weeks, days) of one or more specific years for a certain region is called Sequential BHC and aims to provide the seasonal characterization of conditions of BH throughout the period in question, with this information being of great relevance for decision-making in the agricultural sector.

Pereira et al. (2002) mention that the water balance of crops aims to understand the water balance conditions in the soil covered by a type of vegetation, considering its development phases. In this situation, the plant does not always completely cover the soil and its leaf area (transpirant surface) varies with age (days after planting or emergence).

The BHC is an accounting system for monitoring soil water and results from the application of the principle of mass conversion to water in a volume of vegetated soil. The variation in storage (ΔA) over a period of time represents the balance between water inputs and outputs of the controlled volume (Pereira et al., 1997).

The soil is not a passive reservoir, that is, as it dries, water becomes more strongly retained in it, making it increasingly difficult to extract it from its interior. This means that plants have to spend more energy capturing this water, and this expense explains the reduction in plant growth and production under conditions of water restriction in the soil, as the atmosphere is the active agent in the process of using moisture. and the soil performs the functions of storing and moderating the use of water. (Pereira et al., 1997).

The State of Rio de Janeiro, with approximately 44 thousand square kilometers, although located on the coast of the east coast of Brazil, has different climate patterns. You can find a mountain climate, with mild temperatures and high rainfall, regions of valleys and lowlands droughts and coastal regions with excessive rainfall, in addition to others, such as the North and Northwest regions of the State, with very low rainfall. According to the available climate classifications, part of these regions are classified as dry subhumid and parts as dry. However, there is evidence of a process of decreasing rainfall in recent years, with negative implications for activities dependent on water resources in these regions (Marques et al., 2002; Mendonça et al., 2009; André, et al., 2010).

Mendonça et al. (2011), using remote sensing techniques, mapped the variation in the areas occupied by sugarcane cultivation in the North Fluminense region, and concluded that in the six main sugarcane producing municipalities located in the North Fluminense region, there was a drop in the planting area, during the harvest years from 1984/1985 to 2006/2007, of 43,308.33ha. They also concluded that, in the last two harvest years analyzed, there was an increase in the area allocated to sugarcane activity in the municipalities of the region, mainly in Campos dos Goytacazes, São Francisco de Itabapoana and Cardoso Moreira. In total values, the region recovered 24,422.72 ha between the 2000/2001 and 2006/2007 harvest years as a result of the national biofuels policy.

More recently, Barbosa (2019) mapping the areas cultivated with sugar cane in Campos dos Goytacazes, using remote sensing techniques, pointed out a sugar cane planted area of 25,238.34 hectares in that municipality compared to the values calculated by the Brazilian Institute of Geography and Statistics (IBGE) (30,000 hectares) and ``*Companhia Nacional de Abastecimento*`` (CONAB) (19,200 hectares) for the aforementioned crop year.

Therefore, this work aims to apply the sequential climatological water balance methodology and evaluate its effects on sugarcane activity in the North Fluminense region of the State of Rio de Janeiro.

MATERIALS AND METHODS

According to Köppen's climate classification (1948), the climate of the North Fluminense region is classified as Aw, that is, a humid tropical climate, with a rainy summer, a dry winter and a temperature of the coldest month above 18 °C. The average annual temperature is 24.6°C, with a very small temperature range and average annual rainfall of 981.6 mm (INMET 2023). According to Thornthwaite's climate classification (1941), the North Fluminense region is classified as C1dA'a' - Dry Subhumid Megathermal, with little or no water surplus.

Figure 1 shows the North Fluminense Region in reference to the State of Rio de Janeiro and Brazil.

The normal (BHC_NORMAL) and sequential (BHC_SEQ_Decendial / 10 in 10 days) climatological water balances were prepared using an electronic spreadsheet developed at the Escola Superior de Agricultura Luiz de Queiroz – ESALQ, accessed at http://www.leb.esalq.usp.br/aulas/lce306/lce306.html. Reference evapotranspiration (ETP) values were estimated using the equation proposed by Thornthwaite (1948) (Eq.1). The daily meteorological data for the years 2012 to 2023 observed in Campos dos Goytacazes, RJ were obtained from the National Institute of Meteorology - INMET and refer to Automatic Station A607, installed at Colégio Estadual Agrícola Antônio Sarlo (latittude -21.7147; longitude -41.3441; altitude 25 m, referred to Datun WGS84).

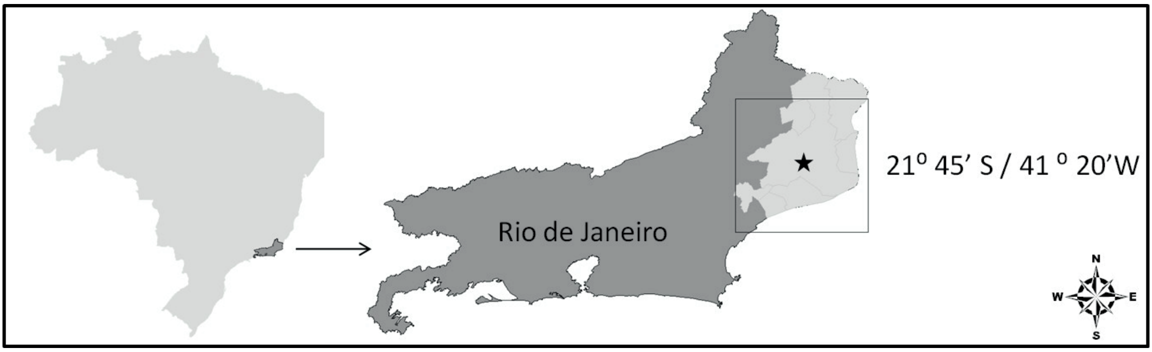


Figure 1: Location of the study area.

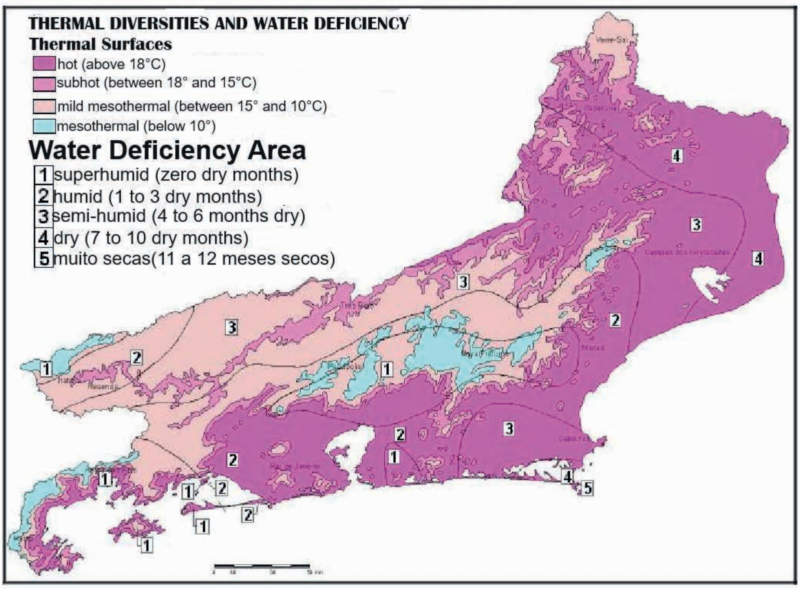


Figure 2: Climate classification of the State of Rio de Janeiro Source: Marques, et al. (2002)

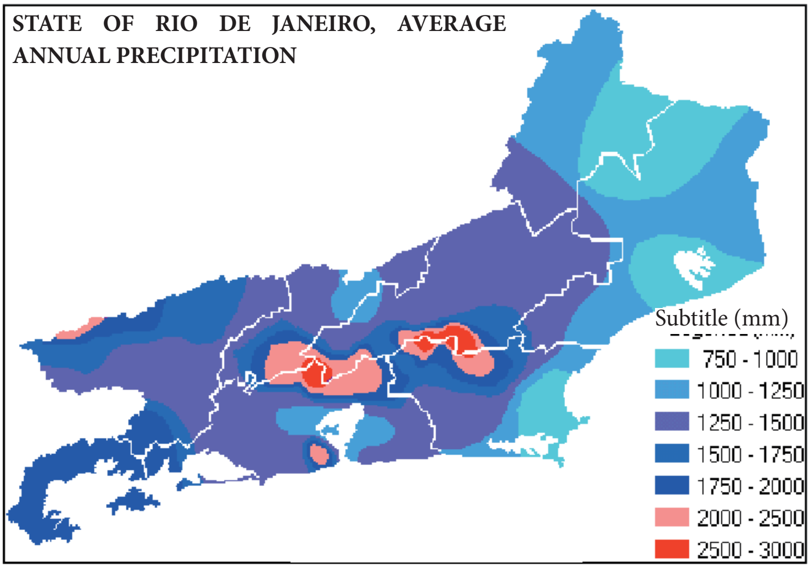


Figure 3. Distribution of annual rainfall in the State of Rio de Janeiro.

Source: Marques, et al. (2002)

$$ETP_{(T)} = 16 * \left(\frac{10 * Tm\acute{e}d}{I} \right)^{a}$$ Eq. 1

Where, ETP is the potential evapotranspiration estimated by Thornthwaite, mm and ``i`` is the index that expresses the heat available in the region;

$$I = \sum_{n=1}^{n} (0{,}2Tm\acute{e}d)^{1.514}$$

And ``a`` is an exponent function of I, calculated by the polynomial function:

$$a = 6.45*10^{-7} * I^3 - 7.71*10^{-5} * I^2 + 1.7912*10^{-2} * I + 0.49239$$

RESULTS AND DISCUSSION

VARIATION OF METEOROLOGICAL ELEMENTS

The official climate classification available in the state today is that published by CIDE (State Information and Data Center), whose summary can be seen in Figure 2. It is noted that the North and Northwest regions of the territory of Rio de Janeiro are presented divided into two sub-regions, one with a sub-humid climate (3) and the other with a dry climate (4), further north. This classification was made using long-term average data, but, considering the trend over the last 40 years, the rainfall regime has been decreasing considerably, thus justifying a study to verify a possible change in the dividing line of this classification.

The map in Figure 3 shows the average annual rainfall distribution for the State of Rio de Janeiro. It is observed that, although there is a lot of rainfall in the mountainous regions and in the southern part of the State, low rainfall is recorded in the North and Northwest regions and in the lake region. These data, in a way, confirm the lack of rainfall in the aforementioned regions, in accordance with the general aspects of the classification presented by CIDE. By map it can also be seen that in the regions mentioned the rainfall varies between 750 mm and 1250 mm annually. However, throughout the year the distribution of rainfall shows that most precipitation occurs in the period from November to January.

Studies carried out at UFRJ (Marques et al., 1988), using data from 1931 to 1975, show the following results regarding the water balance: "On average, at the beginning of the rainy season, in the month of October, precipitation is used almost completely for water replacement. With the water needs in the soil being gradually met, an expansion of the area with excess water was observed in the subsequent months, reaching its maximum in December. But, even in this period of water replacement, the regions represented by the São Fidélis, Campos and São João da Barra stations do not have any month of the year with excess water. In the period from January to March, there is a gradual reduction in water surplus areas in the State, with a slow decrease in their absolute values. During this period, the municipalities of São João da Barra, São Fidélis and Campos are already experiencing water deficiency. The reduction in water surplus areas and the increasing expansion of water deficiency areas is felt more sharply in the April-September period, with lower rainfall being the factor responsible for this behavior. The month of August presents the highest levels of water deficiency in the region".

Figure 4 presents the Monthly Water Balance Extract (BHC_NORMAL) prepared with data from the Climatological Normals of Campos dos Goytacazes, RJ (A = 1960-1990 and B = 1961-2020) prepared by the author with official data from INMET.

In Figure 4, water deficiency can be seen in almost all months of the year, except December. It is important to highlight that the Climatological Normals data refer to the

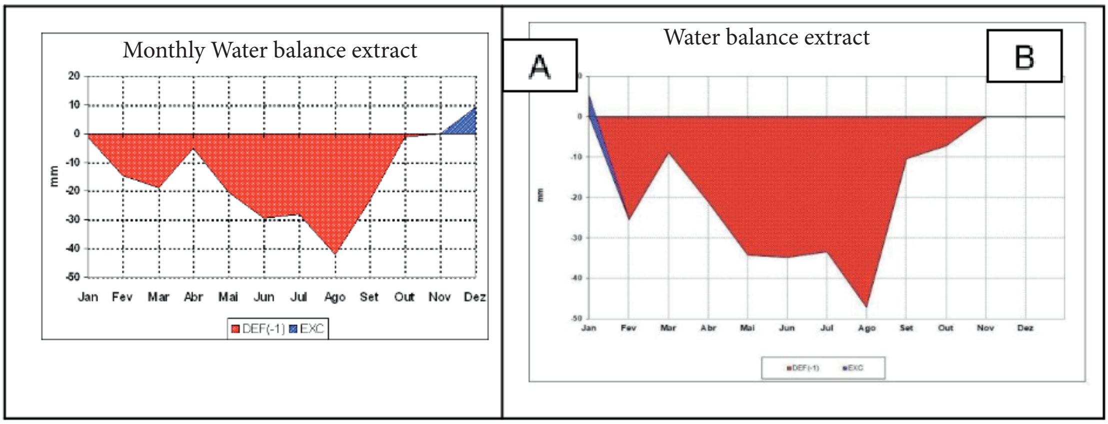
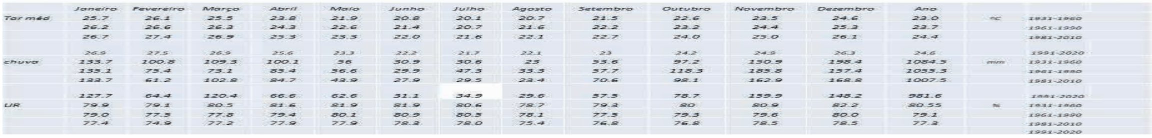


Figure 4: Extract of the Monthly Water Balance prepared with data from the Climatological Normals of Campos dos Goytacazes, RJ (A = period 1960-1990 and B = period 1961-2020). Source: INMET data, prepared by the author.



	Janeiro	Fevereiro	Março	Abril	Maio	Junho	Julho	Agosto	Setembro	Outubro	Novembro	Dezembro	Ano		
Tar méd	25.7	26.1	25.5	23.8	21.9	20.8	20.1	20.7	21.5	22.6	23.5	24.6	23.0	°C	1931-1960
	26.2	26.6	26.3	24.3	22.6	21.4	20.7	21.6	22.2	23.2	24.4	25.3	23.7		1961-1990
	26.7	27.4	26.9	25.3	23.3	22.0	21.6	22.1	22.7	24.0	25.0	26.1	24.4		1981-2010
	26.9	27.5	26.9	25.6	23.3	22.2	21.7	22.1	23	24.2	24.9	26.3	24.6		1991-2020
chuva	133.7	100.8	109.3	100.1	56	30.9	30.6	23	53.6	97.2	150.9	198.4	1084.5	mm	1931-1960
	135.1	75.4	73.1	85.4	56.6	29.9	47.3	33.3	57.7	118.3	185.8	157.4	1055.3		1961-1990
	133.7	61.2	102.8	84.7	43.9	27.9	29.5	23.4	70.6	98.1	162.9	168.8	1007.5		1981-2010
	127.7	64.4	120.4	66.6	62.6	31.1	34.9	29.6	57.5	78.7	159.9	148.2	981.6		1991-2020
UR	79.9	79.1	80.5	81.6	81.9	81.9	80.6	78.7	79.3	80	80.9	82.2	80.55	%	1931-1960
	79.0	77.5	77.8	79.4	80.1	80.9	80.5	78.1	77.5	79.3	79.6	80.0	79.1		1961-1990
	77.4	74.9	77.2	77.9	77.9	78.3	78.0	75.4	76.8	76.8	78.5	78.5	77.3		1981-2010
															1991-2020

Figure 5: Climatological Normal Data for Campos dos Goytacazes, RJ. Source: INMET

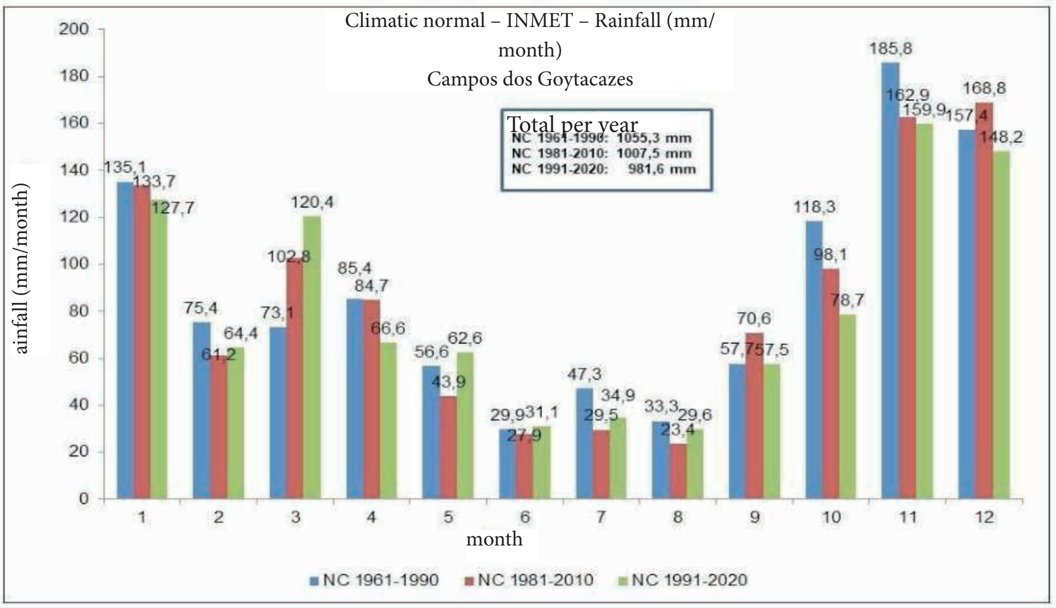


Figure 6: Climatological Normals of Monthly Precipitation in Campos dos Goytacazes, RJ. Source: INMET

period from 1961 to 1990. With the 1991-2020 Climatological Normals this behavior changes, indicating the need for changes in regional agricultural planning.

Figure 5 presents data from Climatological Normals for the 1931-1960 series; 1961-1990; 1981-2010 and 1991-2020 of Average Air Temperature, Rainfall and Relative Air Humidity.

In Figure 5 it can be seen that throughout the period, the Air Temperature, annual average, rose from 23ºC to the current 24.6ºC (an increase of 1.6ºC). That Pluviometric Precipitation (rain) reduced from 1084.5 mm/year to the current 981.6 mm/year (a reduction of 102.9 mm) and that Relative Air Humidity reduced from 80.55% to the current 77.3% (minus 3.25%).

By analyzing these official data, it can be concluded that the region is hotter and drier.

Figure 6 presents, in graphic form, the data on Rainfall and Climatological Normals recorded in Campos dos Goytacazes.

In Figure 6 you can see the variation in monthly rainfall volumes throughout the period, highlighting the high values in the months of November, December and January and the quarter with lower volumes between the months of June and August.

The Figure 7 graphically presents the annual volume of rainfall between the years 1914 and November 2023.

Looking at Figure 7, you can see the reduction trend line of annual rainfall volumes in Campos dos Goytacazes, RJ. It is also observed that of the 108 years recorded, 49 of them present volumes below the Climatological Standard, mainly from the end of the 1970s, worsening in the 2010s, when only in 2 years there were rainfall accumulations above those expected.

The annual rainfall total may not satisfactorily represent the rainfall regime, as high intensity events occurring at specific periods of the year can increase the annual total, often masking a dry year. The way in which rain events occur throughout the year must be interpreted mainly by the daily volume and the consecutive number of days without rain, as this way it can be accounted, in a more realistic way, the soil water balance. Figures 8 and 9 show the number of events and the frequency of these events depending on the intensity of rainfall, between the years 1996 and November 2023, in Campos dos Goytacazes, RJ.

Observing Figure 8, it can be seen that on most days of the year there are no rainfall events and that the predominant classes are of lower intensities (0-10 mm and 10.1-20 mm). It is also observed that high intensity rains are rare, varying depending on an average cycle of 10 to 12 years.

Observing Figure 9, it can be seen that, on average, no precipitation events occur in 75.29% of the year, with the 0-10 mm class being the one with 17.02% of occurrence, followed by 4.07 % of class 10.1-20 mm. On average, the frequency of high-intensity rainfall varies from 0.28 to 0.43%. It can therefore be concluded that the water deficit is of high intensity in Campos dos Goytacazes, RJ.

In the Southeast region, the months of February, April and May represent a transition period between the wet and dry seasons, and the months of September and October represent the transition between the dry and rainy seasons.

TEN-YEAR VARIATION OF THE SEQUENTIAL CLIMATOLOGICAL WATER BALANCE

Figures 10, 11 and 12 show the variation in water storage in the soil in relation to Water Capacity (CAD) and the variation in deficiency, surplus, withdrawal and replenishment of soil water throughout the study period

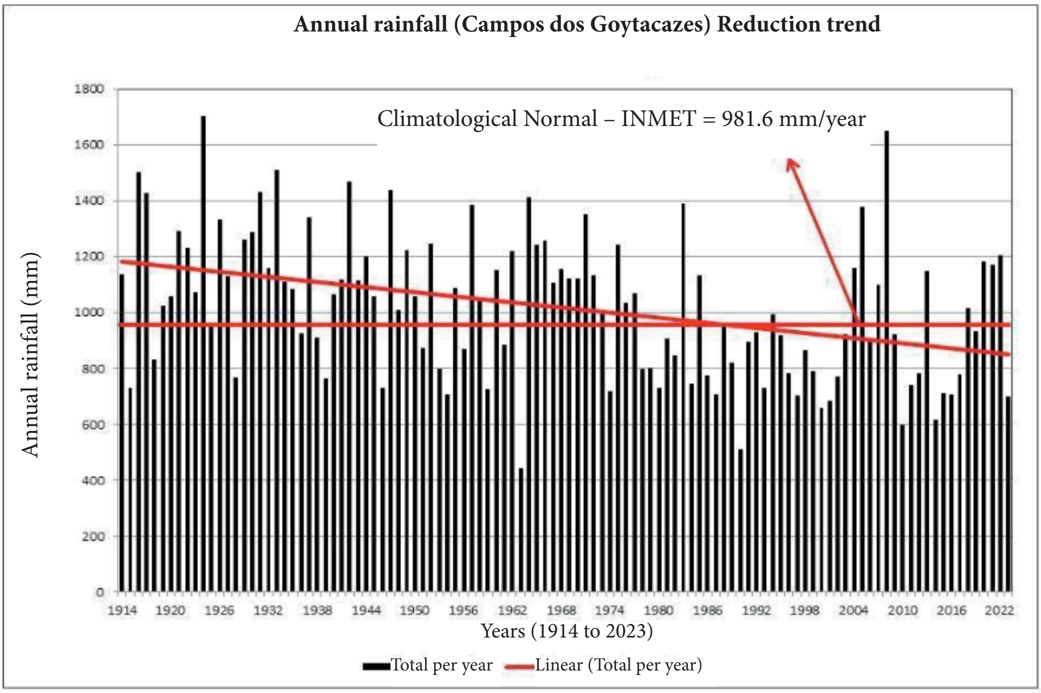
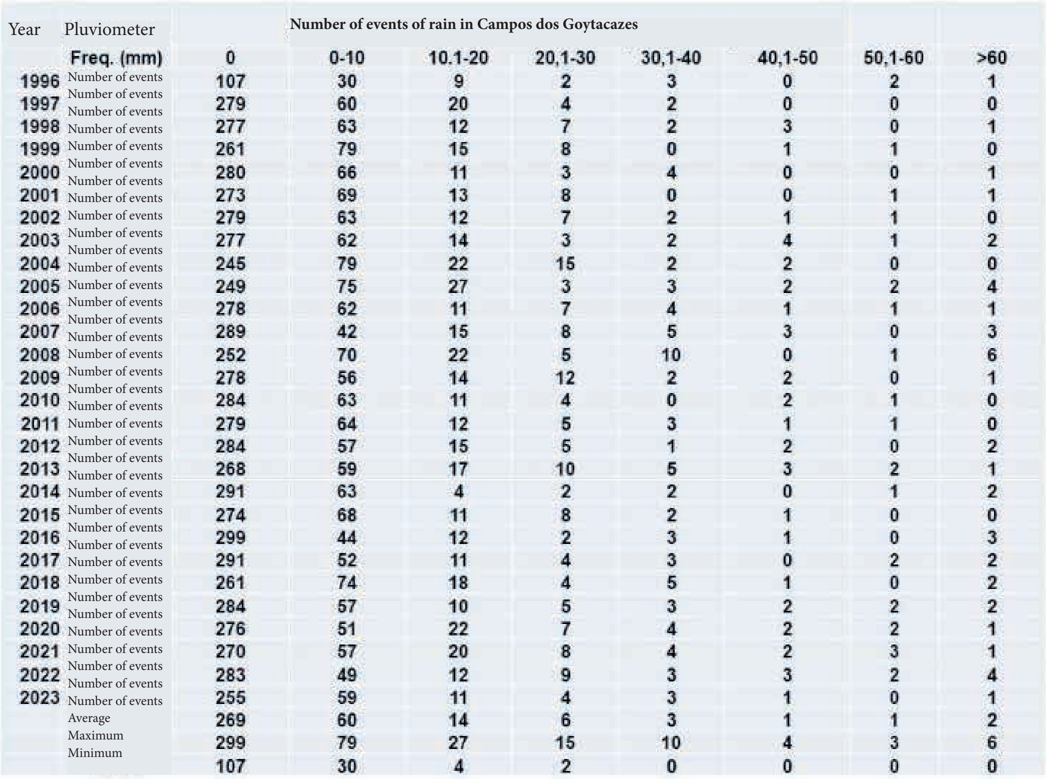


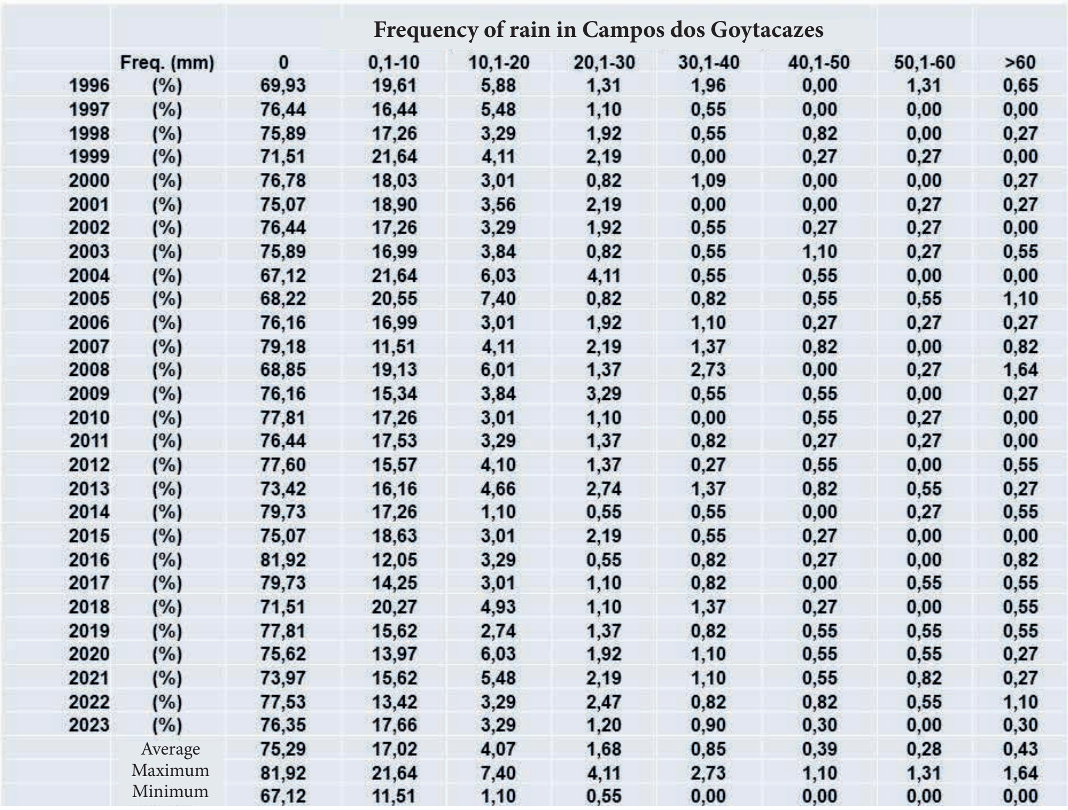
Figure 7: Historical series of annual rainfall accumulations. Source: INMETRO



Year	Pluviometer	Number of events of rain in Campos dos Goytacazes							
	Freq. (mm)	0	0-10	10.1-20	20,1-30	30,1-40	40,1-50	50,1-60	>60
1996	Number of events	107	30	9	2	3	0	2	1
1997	Number of events	279	60	20	4	2	0	0	0
1998	Number of events	277	63	12	7	2	3	0	1
1999	Number of events	261	79	15	8	0	1	1	0
2000	Number of events	280	66	11	3	4	0	0	1
2001	Number of events	273	69	13	8	0	0	1	1
2002	Number of events	279	63	12	7	2	1	1	0
2003	Number of events	277	62	14	3	2	4	1	2
2004	Number of events	245	79	22	15	2	2	0	0
2005	Number of events	249	75	27	3	3	2	2	4
2006	Number of events	278	62	11	7	4	1	1	1
2007	Number of events	289	42	15	8	5	3	0	3
2008	Number of events	252	70	22	5	10	0	1	6
2009	Number of events	278	56	14	12	2	2	0	1
2010	Number of events	284	63	11	4	0	2	1	0
2011	Number of events	279	64	12	5	3	1	1	0
2012	Number of events	284	57	15	5	1	2	0	2
2013	Number of events	268	59	17	10	5	3	2	1
2014	Number of events	291	63	4	2	2	0	1	2
2015	Number of events	274	68	11	8	2	1	0	0
2016	Number of events	299	44	12	2	3	1	0	3
2017	Number of events	291	52	11	4	3	0	2	2
2018	Number of events	261	74	18	4	5	1	0	2
2019	Number of events	284	57	10	5	3	2	2	2
2020	Number of events	276	51	22	7	4	2	2	1
2021	Number of events	270	57	20	8	4	2	3	1
2022	Number of events	283	49	12	9	3	3	2	4
2023	Number of events	255	59	11	4	3	1	0	1
	Average	269	60	14	6	3	1	1	2
	Maximum	299	79	27	15	10	4	3	6
	Minimum	107	30	4	2	0	0	0	0

Figure 8: Number of events x rainfall intensity classes.

Source: LEAG/UENF



Frequency of rain in Campos dos Goytacazes

	Freq. (mm)	0	0,1-10	10,1-20	20,1-30	30,1-40	40,1-50	50,1-60	>60
1996	(%)	69,93	19,61	5,88	1,31	1,96	0,00	1,31	0,65
1997	(%)	76,44	16,44	5,48	1,10	0,55	0,00	0,00	0,00
1998	(%)	75,89	17,26	3,29	1,92	0,55	0,82	0,00	0,27
1999	(%)	71,51	21,64	4,11	2,19	0,00	0,27	0,27	0,00
2000	(%)	76,78	18,03	3,01	0,82	1,09	0,00	0,00	0,27
2001	(%)	75,07	18,90	3,56	2,19	0,00	0,00	0,27	0,27
2002	(%)	76,44	17,26	3,29	1,92	0,55	0,27	0,27	0,00
2003	(%)	75,89	16,99	3,84	0,82	0,55	1,10	0,27	0,55
2004	(%)	67,12	21,64	6,03	4,11	0,55	0,55	0,00	0,00
2005	(%)	68,22	20,55	7,40	0,82	0,82	0,55	0,55	1,10
2006	(%)	76,16	16,99	3,01	1,92	1,10	0,27	0,27	0,27
2007	(%)	79,18	11,51	4,11	2,19	1,37	0,82	0,00	0,82
2008	(%)	68,85	19,13	6,01	1,37	2,73	0,00	0,27	1,64
2009	(%)	76,16	15,34	3,84	3,29	0,55	0,55	0,00	0,27
2010	(%)	77,81	17,26	3,01	1,10	0,00	0,55	0,27	0,00
2011	(%)	76,44	17,53	3,29	1,37	0,82	0,27	0,27	0,00
2012	(%)	77,60	15,57	4,10	1,37	0,27	0,55	0,00	0,55
2013	(%)	73,42	16,16	4,66	2,74	1,37	0,82	0,55	0,27
2014	(%)	79,73	17,26	1,10	0,55	0,55	0,00	0,27	0,55
2015	(%)	75,07	18,63	3,01	2,19	0,55	0,27	0,00	0,00
2016	(%)	81,92	12,05	3,29	0,55	0,82	0,27	0,00	0,82
2017	(%)	79,73	14,25	3,01	1,10	0,82	0,00	0,55	0,55
2018	(%)	71,51	20,27	4,93	1,10	1,37	0,27	0,00	0,55
2019	(%)	77,81	15,62	2,74	1,37	0,82	0,55	0,55	0,55
2020	(%)	75,62	13,97	6,03	1,92	1,10	0,55	0,55	0,27
2021	(%)	73,97	15,62	5,48	2,19	1,10	0,55	0,82	0,27
2022	(%)	77,53	13,42	3,29	2,47	0,82	0,82	0,55	1,10
2023	(%)	76,35	17,66	3,29	1,20	0,90	0,30	0,00	0,30
	Average	75,29	17,02	4,07	1,68	0,85	0,39	0,28	0,43
	Maximum	81,92	21,64	7,40	4,11	2,73	1,10	1,31	1,64
	Minimum	67,12	11,51	1,10	0,55	0,00	0,00	0,00	0,00

Figure 9: Frequency x rain intensity classes. Source: LEAG/UENF

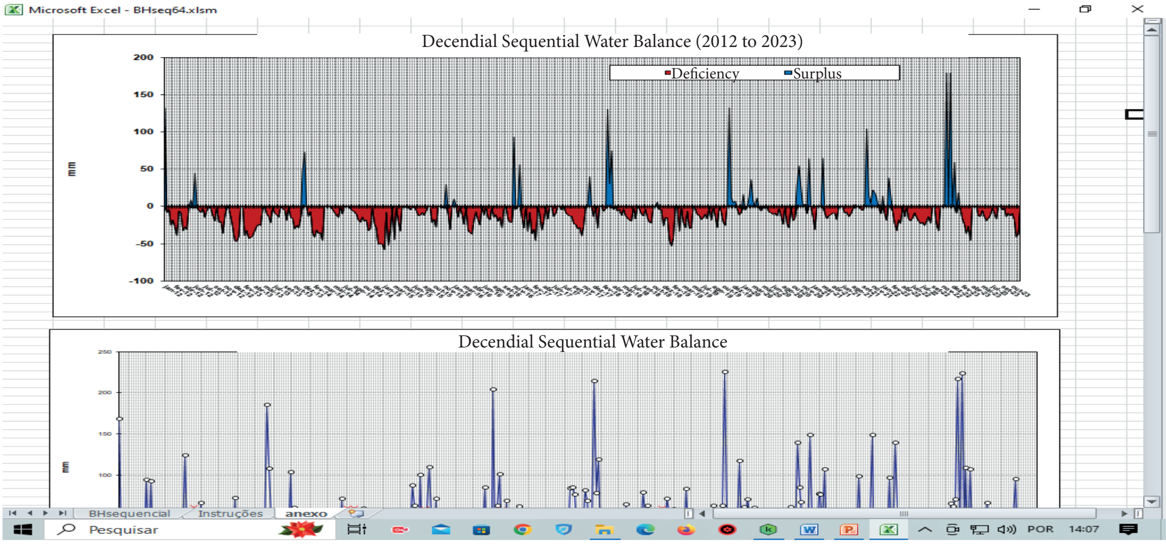


Figure 10: Extract from the decennial sequential water balance.

(January/2012 to November 2023), prepared using the electronic spreadsheet to estimate ETP Thornthwaite (1941) respectively and using Equation 1.

Analyzing Figure 10, water deficiency can be seen in almost all of the 429 ten-year periods evaluated (12 years). The BHC using the ETP estimated by Thornthwaite (Eq.1) identified only 47 decennials with water surplus, the largest being 179.2 mm (30 decennial of November 2022) and another of 179.0 mm in the 20th decennial of December 2022. 2022. The period of greatest water deficiency occurs between the years 2012 and 2019, with the increase in ten-year periods with water surpluses observed from 2020 onwards justified by the increase in high-intensity rain events, as can be seen in Figure 8.

In Figure 11, it can be seen that the water stored in the soil was well below the storage capacity (CAD) in almost all 429 decades. Reaching 100% of CAD in just 47 ten years. It is also observed that the replenishment of water in the soil is extremely lower than in periods of deficiency.

CONCLUSIONS

The analysis of the normal climatological water balance showed a change in the rainfall regime in Campos dos Goytacazes, RJ, with a water deficit in almost all months of the year, indicating the need for readjustment in the region's agricultural planning.

The analysis of the sequential climatological water balance indicated water deficiency in almost all 429 ten-year periods evaluated (12 years) and only 47 ten-year periods with a water surplus, the majority of which, from the year 2020 onwards, were justified by the increase in high rainfall events. intensity, indicating the need for changes in decision-making in the regional agricultural sector.

Finally, it can be concluded that the water deficit is high in all months of the year and that the rainfall regime is inefficient to overcome it.

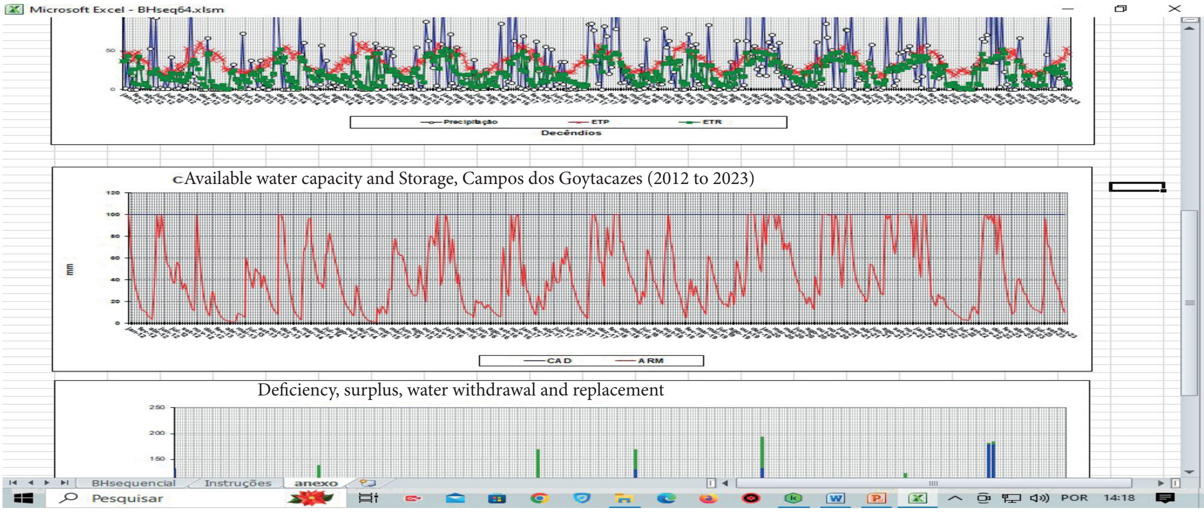


Figure 11: Extract of soil available water capacity.

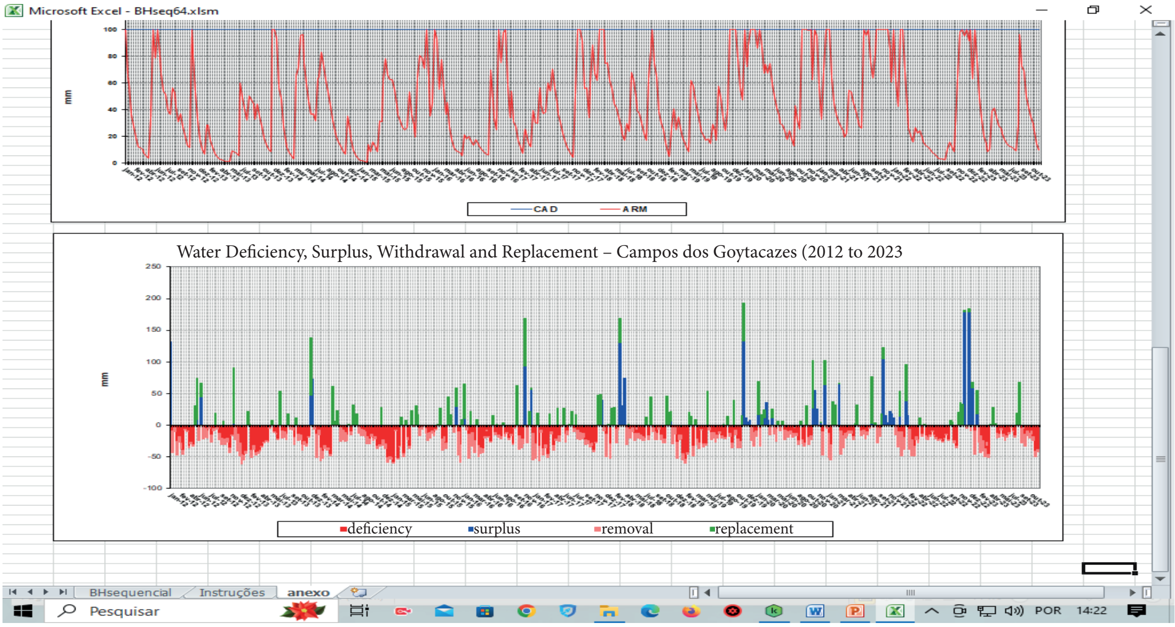


Figure 12: Soil water balance extract.

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