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(Review Article)

Methodological procedures, analysis of the aridity, desertification and semi-arid index for the municipality of Santa Filomena, Piauí, Brazil

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Abstract

The municipality Santa Filomena that it was for is included in the Nucleus of Desertification of Gilbués, since all the other municipalities that are part of the same nucleus are. Data from the IBGE Demographic Census (2010) and the GDP of the municipalities published by IBGE (2009) were used. Social indicators of exclusion of education and income are sought. In addition to being reduced, GDP is far from ideal for a good quality of life. All the social indicators of the semiarid region are very bad. The evidence of the study allows us to conclude that, in fact, in this region, in relative terms, numbers are concentrated that allow the inclusion of these municipalities in the semi-arid area. In addition, the justifications for additional criteria because these municipalities belong to the Nucleus of Desertification of Gilbués, being the only one not yet contemplated with its inclusion in front of all the others already included, including those that belong to the other three nuclei existing in Brazil. The study of the aridity index and its tendency to desertification for the municipalities of Santa Filomena, Barreiras do Piauí, Gilbués and Monte Alegre do Piauí, Brazil was requested by a group of farmers, mayors and lawyers who intend to see the possibility of including these municipalities as a degraded area and its inclusions in the Brazilian semiarid region. The methodology used the calculations of aridity indexes by the water balance method developed by Thornthwaite and Mather (1948; 1955) with a field capacity (CAD) of 100 mm. The water balance graphs were used to demonstrate the variability of water surpluses and deficiencies, replacement and removal of water in the soil and visualization of interannual buoyancy. Electronic spreadsheets of evapotranspiration, evaporation, deficiency and annual water surplus were generated in order to understand their interannual fluctuations as an aid in erosive contributions and aridity indexes. The monthly rainfall for the period 1960-2017 was acquired from the climate bank of Superintendence for the development of the Northeast and from the Empresa de extensión Rural do Piauí where annual fluctuations, anomalies, moving averages, standard deviation, coefficient of variance, absolute maximums and minimums, in addition to studying the fluctuation of average temperatures and calculations of precipitation erosivity indices for the referred municipalities aiming at the objective of municipalities to be included in the semi-arid region and susceptible to desertification. The physiographic aspects, relief, fauna, flora and distance from the sea are evidenced and the edaphic contributions contribute to the incidence of aridity index and susceptibility to desertification in the studied area. The development of monoculture and improper planting techniques contributed to the increase in erosion rates and the tendency for changes in the semi-arid climate with very high risk of susceptibility. Areas identified as vulnerable to desertification, due to the lower aridity index, may not be located in the degraded area, and areas that present a higher aridity index and are not identified as vulnerability processes may be degraded to the point of being considered desertified areas. This variability may occur due to inappropriate use of the soil and environment. Temperature influences evapotranspiration, that is, the loss of water to the atmosphere, because the higher the temperature, the greater the evapotranspiration and, consequently, the lower the aridity index and,

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therefore, the greater the susceptibility to desertification. Possibly anthropic factors, the lack of afforestation in the beds of ponds, lakes, rivers, streams, streams, dams and water tables, the vertical construction and compaction of urban and rural soil plus transient meteorological systems and local factors may have contributed to periods (months, years) with greater variability, however it is known that depending on the season, summer or winter, evapotranspiration and evaporation can really vary, as they are directly related to the seasons with higher and lower precipitation, variability in air temperature, air humidity between other variables such as solar radiation, cloud cover, wind speed and vapor saturation pressure, which can reduce the evaporative process.

Keywords: Climatic variability; Hydric balance; Surpluses and deficiencies; Evapotranspiration; Evaporation

1. Introduction

Knowledge of climatic variables is of paramount importance for the development of human activities and even for their survival, especially in areas with notable climatic variation. In this scenario, the Northeast of Brazil (NEB) is inserted, which has as the most striking element of its landscape the irregular rainfall regime with its distribution in space and time. This fact generates a concentration of rain in 4 to 5 months throughout the year, leaving the rest with low or no rain. It is also mentioned that the region has high average temperatures and high total evapotranspiration, and an expressive water deficit.

The United Nations Convention to Combat Desertification approved the use of the aridity index (AI) which is the ratio between total annual precipitation and total annual evapotranspiration, with arid to dry sub-humid lands having an AI between 0.03 and 0. 65 except for the polar and subpolar regions according to [77].

Of the consequences that could occur in the characteristics of the current climate, the serious ones would be the increase in aridity rates and areas of desertification due to the increase in water deficit, in addition to extreme events that would be associated primarily in regions that are already arid or semi-arid, like the Brazilian semiarid region [72].

AI has been used to delimit areas susceptible to desertification worldwide. The said index varies from 0.05 to 0.65 and, therefore, the susceptibility from very high to moderate according to the author [98].

[115] developed the humidity, aridity and water indexes aiming at the climatic classification and the authors [116] performed the water balance having o output variables the total annual potential evapotranspiration, water deficit, water surplus of water in the soil, among others. The authors indicated that the Aridity Index (Ia) is the ratio between the annual deficit of humidity and the potential evapotranspiration; the Moisture Index (Iu) is the annual surplus of water in the soil divided by the potential evapotranspiration; and the Effective Moisture Index (Im) is (Iu) multiplied by 100 minus 0.6 times (Ia) multiplied by 100.

The causes of desertification in the world include overgrazing (680 million hectares), deforestation (580 million hectares), inadequate agricultural management (550 million hectares), and consumption of firewood as fuel (137 million hectares), industry and urbanization (19.5 million hectares) [118].

The annual global economic costs of desertification are known to exceed US$ 42 billion, while to combat desertification only an average of US$ 10 to 20 billion is spent per year [71].

It is possible that changes in climate change temperature and precipitation, and that they increase the variability of precipitation events, which could cause more intense and frequent floods and droughts in accordance with [29]. Studies have shown that the frequency and persistence of droughts should be one of the consequences of global warming according to the authors [29]. It should be noted that in northeastern Brazil (NEB) agricultural activities are mostly based on precipitation. If these forecasts come true, especially the social and economic sectors, the Brazilian northeast (NEB) will suffer from these results.

Some vulnerabilities occur due to the limited capacity to resist droughts, for example, which manifest themselves as socioeconomic crises. These crises have been advancing over time, largely due to the rhythm and form of demographic and productive occupation of the great interior of the Brazilian semi-arid region and, in particular, of Paraíba, causing serious overloads to the fragile environment and the natural resources that are relatively poor as stated [109].

[99] studying the Brazilian semi-arid region that represents an ecologically unstable environment due to inadequate use and overexploitation of natural resources by strong human action, these factors make the municipality of São João

do Cariri to be considered quite susceptible to desertification. The atmospheric circulation processes predominant in this region also contributed significantly to desertification. The analysis of the spatial and temporal variability of rainfall provides relevant information for the diversified sectors in helping the use of rainwater and its storage, in the economy and agriculture of the municipality. During the 99 years studied, extreme annual rainfall totals were recorded in 1985, when it rained 1.163.2 mm, and in 1998, when the annual total recorded was 124.8 mm. of the meso and large-scale phenomena active during the period studied.

[63] demonstrated that the spatial variation of meteorological variables: water deficit, water surplus and the Aridity, Humidity and Water indices as a function of the available water capacity (CAD's) at the levels of 75, 100, 125 and 150 mm performed by the method of the BHC proposed by [115, 116] are not the same in the State of Piauí. Through this analysis it was found that there were small oscillations in these variables as a function of the CAD's studied, proven by the space-time variability of the pluviometric indices together with the high oscillation of the potential evapotranspiration.

[113] studying desertification in the municipality of São João do Cariri/PB makes an analysis of socioeconomic and environmental vulnerabilities, revealing the interrelationship between the vulnerability of rural families with the phenomenon of desertification. The results obtained were social vulnerability, 44.85%, which is considered high, and economic vulnerability was 13.05%, which is considered low. Regarding technological vulnerabilities and droughts, the values found were, respectively, 30.03% and 17.68% considered moderate. The analysis of socioeconomic and environmental vulnerabilities in São João do Cariri made it possible to diagnose the susceptibility of families to the phenomenon of desertification.

The processes of surface erosion of soil particles are caused by the actions of wind and water, causing or causing wind or water erosion. Water erosion is the most important and worrying one due to the predominance of the tropical climate according to the statement by [14].

In the Brazilian Northeast, most activities are based on the exploitation of natural resources, and in particular, on the extractivism of vegetation cover, on the overgrazing of native areas and on agricultural exploitation through soil management practices that are often inadequate according to [95].

In several regions of Brazil there have been serious problems of environmental degradation, caused by both anthropic changes and natural processes. Among the natural processes, water erosion can be highlighted as one of the most important forms of soil erosion, especially when there is no planning and disrespect for the ability to use natural resources as stated by [12].

The impacts caused by water erosion are the impoverishment of the soil due to the loss of nutrients and organic matter, silting and contamination of water bodies by the displacement of fertilizers and pesticides, causing direct changes in the fauna and flora according to the authors [14] and [84]. Also according to [84] soil erosion is analyzed as a process of natural origin with the purpose of landscape formation and soil renewal.

[101] states that the process of desertification, in general, occurs in areas where the ratio between precipitation and potential annual evapotranspiration is less than 0.65, this corresponds to arid, semi-arid and dry sub-humid areas, in which a combination of of anthropic and natural factors act to accelerate or not the erosive process.

1.1. Goals

1.1.1. General

Analyze the variability of the trend fields of mean air temperature, precipitation, potential evapotranspiration and actual evaporation, aridity indices and their climate classifications with level of susceptibility; estimation of annual soil losses through the universal equation and erosivity factors.

1.1.2. Specific

Evaluate the impacts of the studied elements and their possible climate and erosion changes.

1.1.3. Justification

With the development and completion of this research, it is expected that variations in the trend fields of mean air temperature, precipitation, potential evapotranspiration and actual evaporation, aridity indices and their climate classifications with susceptibility level will be determined and explained; estimation of annual soil losses through the universal equation and erosivity factors in terms of regional and local scale. We believe in a better deepening of knowledge and the contribution of the universe of future generations, regarding the climatology of the region and changes in weather and climate.

The State of Piauí already has 185 of its municipalities incorporated into the Brazilian semi-arid region. The extreme south of the state still has a small number of municipalities that are part of the Gilbués Desertification Nucleus, which has not yet been recognized by the Ministry of National Integration, which greatly penalizes a significant contingent of Piauí residents who survive under the same conditions or more severe than those conditions that many municipalities already in the semi-arid region experience. Therefore, the population that lives in this region does not benefit from the different policies that can be contemplated, in this way it comes to corroborate to worsen the existing state of poverty in the extreme south of the state of Piauí.

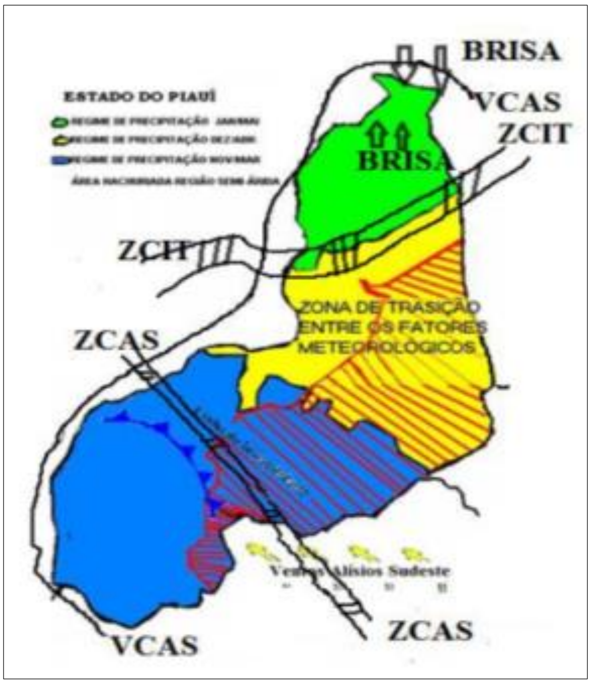
Therefore, expanding and updating the regional delimitation, to adapt the operation of the Constitutional Fund for the Development of the Northeast (FNE), finalizing the inclusion of the entire Desertification Nucleus in the area of operation of the Superintendence for the Development of the Northeast (SUDENE), serving as a basis for the public policies of the Ministry of National Integration (MI) for the semi-arid region.

2. Material and methods

The municipality is located in the micro-region of Alto Parnaíba Piauiense, comprising an area of 5,369 km2, bordered by the municipalities of Ribeiro Gonçalves and the state of Maranhão to the north, to the south with Gilbués, to the west with municipalities in the state of Maranhão and, to east, with Gilbués, Baixa Grande do Ribeiro and Ribeiro Gonçalves. The municipal seat has the geographic coordinates of 09º06'44'' south latitude and 45º55'20'' west longitude of Greenwich with an average altitude of 277 meters above sea level.

Source: Medeiros (2022).

Figure 1 Geographic location of the municipality of Santa Filomena – PI



Source: [61].

Figure 2 Rainfall regimes and main factors causing rain in the state of Piauí

The provoking and/or inhibiting factors of rain are predominant for the municipality of Santa Filomena, are the formation of instability lines carried by the Southeast/Northeast trade winds, heat exchange, traces of cold fronts when they penetrate more active, convective cluster formations, contributions of high-level cyclonic vortex formations, South Atlantic Convergence Zone, orography and local effects, are factors that increase the transport of water vapor and moisture and consequently the cloud cover as quote from [61] (Figure 2).

Normally, the rains are of moderate intensity (regular weather, around seven to eight hours of discontinuous rains daily), followed by irregularities due to the failures of the active meteorological systems. It should be noted that the occurrence of summer periods (occurrences of several consecutive days without rain during the rainy season) in the four-month period (December, January, February, March) is expected. Its magnitude varies depending on the season and weather factors disabled. Occurrences with summer periods exceeding nineteen (19) days per month have been recorded in the time interval that occurred within the four-month period. The rainy season begins in October with pre-season rains (rainfalls that occur before the rainy season) and lasts until April, in atypical years, the month of May has rains above the normal pattern. The rainy quarter is centered on the months of December, January, February and March. The dry four-month period is recorded in the months of June, July, August and September according to [61].

According to the climate classification by [49] Santa Filomena has an "Aw" climate, hot and humid tropical, with rain in the summer and dry in the winter, this classification is in agreement with [3]. The climate classification according to the Thornthwaite and Mather model for the dry scenario is of the semi-arid type, in the regular scenario there is the Sub-humid climate, for the rainy and medium scenarios the Sub-humid climate predominates.

The methodology used average monthly and annual rainfall data acquired from the database of the Northeast Development Superintendence [111] and the Technical Assistance Company of the state of Piauí [30] for the period from 1960 to 2017.

The climatological water balance (BHC) used calculates the availability of water in the soil for the different types of cultivation. It counts precipitation against potential evapotranspiration, taking into account the field capacity of soil water storage (CAD). The model used to determine the water balance was the one proposed by [115, 116] and its calculation structure was carried out by electronic spreadsheets in accordance with [61]. The BHC calculation was performed only with data of average precipitation and average monthly air temperature with available water capacity (CAD) of 100 mm.

Average air temperature values estimated by the estima_T software [22, 23] were used. Estima_T is a software to estimate air temperatures in the Northeast Region of Brazil. This region was divided into three areas: area 1 comprising the states of Maranhão and Piauí; area 2 specifies for the states of Ceará, Rio Grande do Norte, Paraíba and Pernambuco and area 3 for the states of Alagoas; Sergipe and Bahia. For all regions (1, 2 and 3) the coefficients of the quadratic function were determined for the monthly average, maximum and minimum temperatures as a function of the local coordinates: longitude, latitude and altitude according to the authors [23] given by:

$$T = C0 + C1\lambda + C2\O + C3h + C4\lambda 2 + C5\O 2 + C6h2 + C7\lambda\O + C8\lambda h + C9\O h$$

On what:

C0, C1,..., C9 are the constants;
λ, λ2, λ Ø, λ h longitude;
Ø, Ø2, λ Ø latitude;
h, h2, λ h, Ø h height.

They also estimated the temperature time series, adding to this the temperature anomaly of the Tropical Atlantic Ocean [22].

$$Tij = Ti + AATij \quad i= 1,2,3,...,12 \quad j= 1950, 1951, 1952,....2015$$

On what:
i= 1, 2, 3,...,12
j= 1950, 1951, 1952, 1953...2015.
An electronic spreadsheet was elaborated with the respective monthly and annual temperature data. The gaps were filled in, followed by their homogenization and consistencies. To determine the erosivity factor, the equation proposed by [121] and [122, 123] defined as:

$$EI_{30} = 67{,}355\left(\frac{r^2}{P}\right)e^{0,85}$$

Being:

EI30 the monthly average of the rainfall erosivity index (MJ. mm $ha^{-1}.h^{-1}$);
r the average monthly rainfall (mm);
p the average annual precipitation (mm).

The R factor (rainfall erosivity) allows the assessment of the erosive potential of precipitation in a given location, making it possible to know the capacity and potential of rain to cause soil erosion, so that adequate management and correct occupation of the same can be carried out according to Authors' comments [10] and [70]. The calculation of this factor is the sum of the monthly erosivity values, according to the equation:

$$R = \sum_{1}^{12} EI_{30}$$

2.1. Calculation of potential evapotranspiration (ETP)

Another way of estimating the potential evapotranspiration (ETP) used in the methodology requires only data on average monthly air temperature and maximum insolation expressed in mm/month. The ETP is defined as follows, according to [115, 116].

$$(\mathrm{ETP})\mathrm{j} = \mathrm{Fj} \,.\, \mathrm{Ej}$$

Where;

Ej represents the unadjusted potential evapotranspiration (mm/day) and summarized as follows:

$$Ej = 0{,}553\ (\frac{10.Tj}{I})^{a}$$

On what:
Tj represents the monthly mean air temperature for the month (°C)
I is the annual heat index defined by:

$$\mathrm{I} = \sum_{j=1}^{12} ij$$

Therefore, the thermal index of heat in the month is given by:

$$ij = (\frac{Tj}{5})^{1{,}514}$$

Finally, the exponent “a” is a cubic function of this annual heat index, expressed as follows:

$$a = 6{,}75x10^{-7} - 7{,}71x10^{-5}I^{2} + 1{,}79x10^{-2}\ I + 0{,}49$$

The correction factor is defined as a function of the number of days in the month Dj (in January, Dj= 31; in February, Dj=28; etc.) and the maximum insolation on the 15th of the month J (Nj), considered representative of the average of that month, defined by:

$$Fj = \frac{Dj.Nj}{12}$$

To calculate the maximum insolation on the 15th, the following expression was used:

$$Nj = \left(\frac{2}{15}\right)[\mathrm{arc.}\cos(-tag\emptyset.\,tag\delta)]$$

Where;
Ø Location latitude;
δ Declination of the Sun in degrees, for the considered day; defined by:

$$\delta = 23{,}45^0 sen[360(284 + \mathrm{d})/365]$$

On what,
"d" is the serial number, in the year of the day considered (Julian day).

The estimate of potential evapotranspiration is only valid for a monthly average air temperature below 26.5°C. When the average temperature of that month is equal to or greater than 26.5°C, [115, 116] assumed that Ej is independent of the annual heat index and an appropriate Table is used for its estimation.

2.1.1. Aridity index

The aridity index (AI) was calculated using the formula suggested by the United Nations Environment Program (UNEP - 118), which has been used to classify land susceptible to desertification processes, whose equation is given by:

$$IA = \frac{\Pr}{ETP}$$

Where;
Pr is the average annual precipitation (mm $year^{-1}$)
ETP is mean annual potential evapotranspiration (mm $year^{-1}$).

Thus, the AI was calculated for the municipality under study with the monthly and annual precipitation data and the average air temperature data, and the monthly average evapotranspiration was calculated by the climate water balance method in accordance with [115, 116]. Therefore, the electronic spreadsheet developed by [62] was used to calculate the water balance. The climate classification of a given location must be in accordance with the AI values shown in Table 2.

Table 1 Climatic classification according to the aridity index (AI) values

Types of Weather	Aridity index (IA)
Hyperarid	IA≤0.03
Arid	0.03<IA≤0.2
Semiarid	0.2<IA≤0.5
Dry sub-humid	0.5<IA≤0.65
Sub-humid	0.65<IA≤1.0
Damp	IA>1.0

The degree of desertification is associated with susceptibility according to the IA index, plus the severity of the dry season, demographic pressure and type of use of natural resources, as well as the country's level of development and the quality of preventive measures [33]. Knowing the historical meteorological series of precipitation and average temperature and the AI, it is possible to characterize the availability of water and the planning for its use. It is also possible to highlight the annual periods that will be critical, with water losses or surpluses in accordance with [110].

Table 2 Classification regarding the level of susceptibility to desertification using the Aridity Index, adapted from the methodology of Matallo Júnior (2001)

Level of susceptibility to desertification	Aridity index
Superior to moderate	IA>0.65
Moderate	0.51 < IA < 0.65
High	0.21< IA < 0.50
Very tall	0.05< IA < 0.20
Lower to very high	IA<0.05

2.1.2. Physiographic aspects

The soils in the region, resulting from the alteration of sandstones, siltstones, shale, conglomerate, limestone and silexite, are thick, young, influenced by the underlying material, comprising yellow, alic or dystrophic latosols, medium texture, associated with quartz sands and/or red-yellow concretionary podzolic, plinthic or non-plinthic. The vegetation is subdeciduous tropical cerrado phase, with coca forest [46].

The predominant morphological feature is the wide reworked tabular surface, flat or slightly undulating, limited by abrupt scarps that can reach 600 m, showing relief with recessed and dissected zones [46].

2.1.3. Geology

As shown in figure 2, the geological units that occur within the municipality comprise the sedimentary covers of the Parnaíba Basin, described below. The Pedra de Fogo Formation gathers sandstone, shale, limestone and silexite. At the base of this sequence is the Piauí Formation, comprising sandstone, shale, siltstone and limestone.

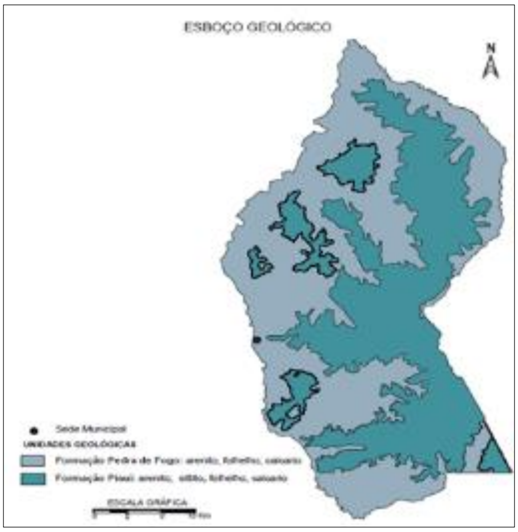


Figure 3 Geological sketch of the municipality

2.2. Water resources

2.2.1. Surface waters

The surface water resources generated in the state of Piauí are represented by the Parnaíba river basin, the most extensive among the twenty-five (25) basins of the Northeast Region (with an area of 330,285 km2, equivalent to 3.9% of the national territory) and covering the state of Piauí and part of Maranhão and Ceará.

The region occupies an area of 330.285 km2, equivalent to 3.9% of the national territory, and drains almost all of the state of Piauí and part of Maranhão and Ceará. The Parnaíba River is 1400 km long and most of the tributaries located downstream of Teresina are perennial and supplied by rainwater and groundwater. After the São Francisco River, it is the most important river in the Northeast.

Among the sub-basins, those constituted by the rivers stand out: Balsas, located in Maranhão; Potí and Portinho, whose sources are located in Ceará; and Canindé, Piauí, Uruçuí-Preto, Gurguéia and Longá, all in Piauí. It should be noted that the Canindé River sub-basin, despite having 26.2% of the total area of the Parnaíba basin, drains a large semi-arid region.

The state of Piauí is part of the Polígono das Secas, it does not have a large number of dams. The most important are: Boa Esperança, located in Guadalupe and damming five billion cubic meters of water from the Parnaíba River, has been providing great benefits to the population by raising fish and regulating the flow of the river, which will prevent large floods, in addition to improve the navigation possibilities of the Parnaíba river; Caldeirão, in the municipality of Piripiri, where large agricultural projects are developed; Cajazeiras, in the municipality of Pio IX, is also a guarantee against water shortages during droughts; Ingazeira, located in the municipality of Paulistana, on the Canindé river and; Barreira, located in the municipality of Fronteiras.

The main watercourses that drain the municipality under study are: the Parnaíba, Riachão and Riozinho rivers, and the Ouro, Taquara, dos Angicos, Sucuruju and Zealand streams.

2.2.2. Groundwater

Santa Filomena is distinguished only as a hydrogeological domain by the sedimentary rocks of the Parnaíba Basin, represented, from bottom to top, by the Piauí and Pedra de Fogo formations. The Piauí Formation is lithologically made up of sandstones, with intercalations of siltstones, shales and limestones. O it is present in about 50% of the area of the municipality, it is an important option from the hydrogeological point of view.

The Pedra de Fogo Formation, due to its lithological characteristics, with a predominance of clayey layers and intercalations of flint beds, which are impermeable rocks, presents little hydrogeological interest.

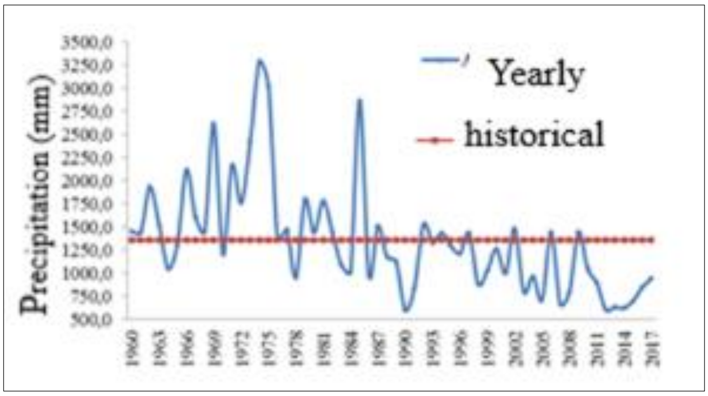
3. Results and discussion

3.1. Precipitation

For the authors [110; 4 and 05] the previous knowledge of the procedure of the rainfall regime in monthly and annual scales, in terms of intensity, duration and distribution, as well as information on the surplus and local and regional water deficit are valuable data, which condition the type of natural vegetation in a given region, the type of farm to be developed, enhances non-irrigated agriculture, influences the hydrological cycle, and allows for a glimpse of solutions to water problems.

Low intensity rain is of great importance for agriculture, as it is more conducive to maintaining soil moisture, if this rain reduces the soil becomes increasingly dry, without vegetation, becoming unprotected. This confirms the situation that the region is going through, which is included in an area that has a high susceptibility to desertification according to the Report of the National Program to Combat Desertification.

Figure 4 shows the distribution of annual and historical average rainfall for the municipal area of Santa Filomena - PI in the period 1960-2017. With irregular rainfall and high interannual variability, the study area has an annual rainfall of 1357.6 mm in fifty-eight (58) years of observed and recorded rainfall, twenty-seven (27) years stand out with rainfall rates below the average, ten (10) years with rainfall between normality and twenty years (21) with above average rainfall. These irregular oscillations are in accordance with the studies in [44, 45] and as described in [54].



Source: Medeiros (2022).

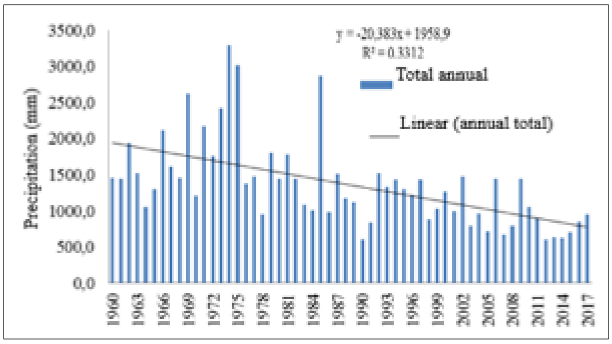
Figure 4 Distribution of annual and historical average precipitation for the municipal area of Santa Filomena - PI in the period 1960-2017

The years 1967 to 1975 and 1985 stand out, in which the precipitation was of extreme values, exceeding the average, except for the year 1971, which rained below average. Between 1998 and 2017, rainfall rates were below the climatological average, except for the years 2002, 2007 and 2010 where rainfall rates flowed close to the average.

Irregular variabilities depend on the factors acting in the years, these factors are extreme events, action of meso, large and large scale phenomena followed by local and regional contributions that help or reduce rainfall rates. [60, 61].

Rainfall monitoring is a global concern and, therefore, policies for forecasting total rainfall have been adopted around the world with a view to storing and impounding rainwater. In this sense, several warning mechanisms regarding the scarcity or excess of water resources become increasingly common, especially for the poultry and agricultural sector. According to [112] who believe in the evidence between the distribution of meteorological variables and the modes of climate variability in different regions of the globe.

Figure 5 shows the distribution of average annual rainfall and its lineares trend for the municipal area of Santa Filomena - PI in the period 1960 - 2017. This figure has a negative angular coefficient of moderate significance, demonstrating that the trend is of reduction of rainfall in the coming years.



Source: Medeiros (2022).

Figure 5 Distribution of average annual precipitation and its lineares trend for the municipal area of Santa Filomena - PI in the period 1960 - 2017

Other expected problems are the reductions in rainfall, which may reach a range of 60% of the monthly values. If the estimates are correct, water storage reservoirs will become obsolete, significantly restricting access to potable water. The fauna and flora will undergo changes, and some species may become extinct [56], which corroborates the current study.

Table 3 Statistical variability of precipitation in the municipality of Santa Filomena – PI

Variability of parameters (mm)						
Months	**Maximum**	**Minimum**	**Median**	**Mean**	**Standard deviation**	**Coefficient of Variance**
January	569.5	70.5	248.5	234.4	128.0	0.546
February	646.0	65.0	184.0	263.8	130.4	0.494
March	637.1	0.0	270.5	225.9	126.6	0.560
April	611.9	0.0	152.0	185.3	109.1	0.588
May	292.3	0.0	0.0	48.4	57.1	1.180
June	83.9	0.0	0.0	6.6	15.5	2.349
July	30.3	0.0	0.0	1.1	4.1	3.752
August	10.0	0.0	0.0	0.3	1.3	4.006
September	106.5	0.0	0.0	10.7	21.6	2.023
October	315.2	0.0	135	66.8	64.5	0.966
November	410.8	0.0	86.4	122.1	80.3	0.658
December	737.0	0.0	96.4	192.0	121.0	0.630
Annual	3290.0	598.2	1172.8	1357.6	598.1	0.441

Source: Medeiros (2022).

Table 3 shows the statistical variability of the parameter of absolute maximum and minimum rainfall, median, mean, standard deviation and coefficient of variance for the studied area for the period 1960 - 2017.

In the absolute maximum values, the months from June to August stand out with low rainfall, in the other months there are records of the high volumes that occurred and in a short time interval, it should be noted that these values have the possibility of returning from 5 to 10 years old. In the absolute minimum values, the months of January and February stand out, which presented anomalous values, these anomalies were due to local and regional transient systems. The median is representative of rainfall indices with greater reliability than the average, the values of the deviations may have variability of reduction or increase in the average values, the coefficients of variance are not representative between the months of May to September.

Studies such as those by the researchers [55, 47, and 48] have shown that the relative frequency of extreme events depends on changes in standard deviation and not just on the mean. [47] assumes that a change in a climate variable that has a probability distribution may result in a change in the form of its distribution. Studies such as those of the authors mentioned above corroborate the present study.

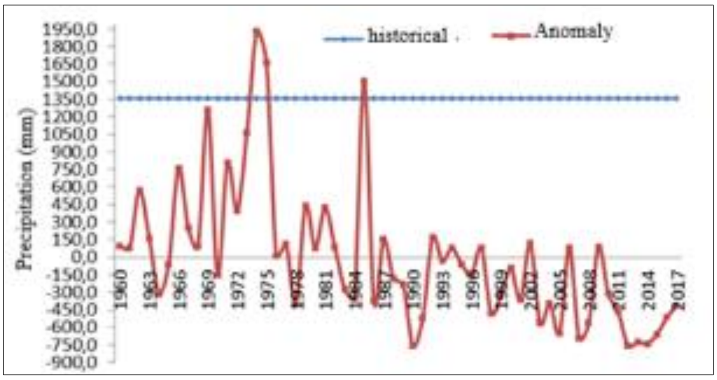
3.2. Precipitation anomaly

Pioneering studies carried out by [120] have already indicated that the anomalous heating of surface waters in the equatorial Pacific influences the droughts in northeast Brazil (NEB). Since then, several studies have been carried out, also presenting evidence of the role played by the Atlantic and Pacific Oceans in the climatic fluctuations in South America as stated by the authors [5] and [101].

The Precipitation Anomalies Index developed by [90] is used to classify positive and negative fluctuations in rainfall anomalies. It is considered a remarkable procedural simplicity index because it only requires precipitation data [34 and 35]. According to [90], precipitation anomalies make it possible to compare precipitation deviations in different regions.

[96] used the anomaly index in order to analyze the annual variability of precipitation from 1928 to 2009 in Alegrete/RS, and to compare the indices obtained from the El Niño Southern Oscillation (ENSO) and Pacific Decadal Oscillation. The authors concluded that the anomaly index was presented as an important tool in the analysis of precipitation in the municipality.

Figure 6 shows the variability of the precipitation anomaly and its historical average for the municipality of Santa Filomena - PI in the period 1960 - 2017. In most years the precipitation anomaly flowed below 1200 mm, also observed negative anomalies from the year 1988 to 2017 except the years 1991, 1994, 1997, 2002, 2006, 2009.



Source: Medeiros (2022).

Figure 6 Precipitation anomaly and its historical average for the municipality of Santa Filomena - PI in the period 1960 -2017

This information is very important in agricultural planning, providing support for alerts in reducing the risk of production losses. Analyzes of this nature are reported in several studies of rainfall analysis of different municipalities or regions [75, 107, 100 and 85]. Which corroborates with this study.

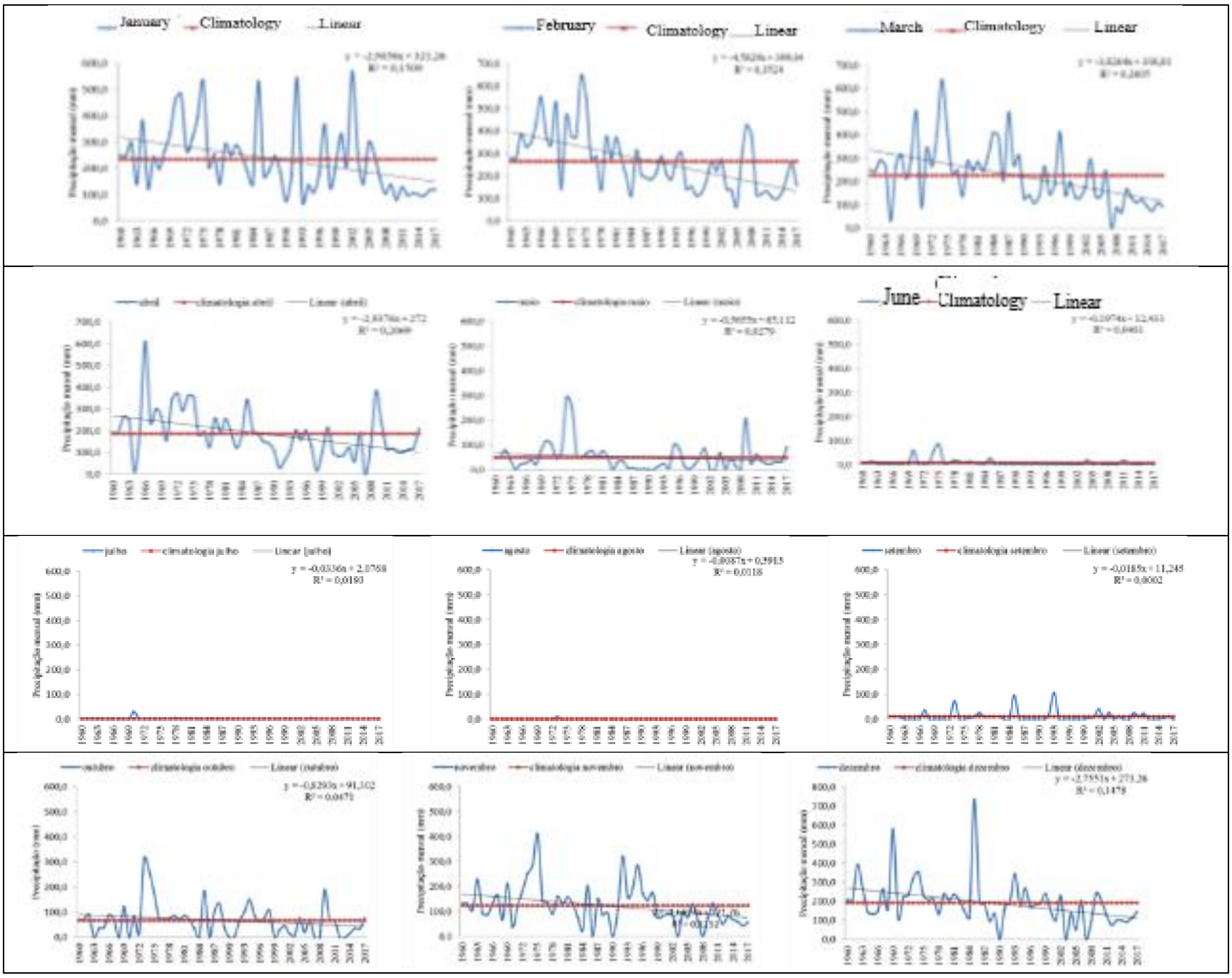
Regarding precipitation, forecasts indicate that there should be a reduction in the tropical and subtropical region and an increase in the average of the regions of higher latitudes. For the cerrado region where rainfall fluctuates according to large-scale phenomena (El Niño/La Niña) [64] the historical averages even in times of rainy season oscillate within and below normality, the spatial and temporal variability is influenced by the weather systems operating at the time, its tendency and that rainfall rates persist below the climatology in future scenarios. [97] in their study in Minas Gerais in the semi-arid region demonstrates that the variability of the rainy season depends solely and exclusively on the factors that provoke rain.

Information on anomalous variability can be useful to guide local socioeconomic activities and reduce the risk of economic losses resulting from fluctuations in rainfall.

3.3. Rain distribution analysis in monthly schedules

Figure 7 shows the variability of the temporal distribution of linear regression and climatologies of monthly rainfall from January to December in the period from 1960 to 2017, with the equation of the line and the values of R2 for the area under study.

The distribution of annual mean rainfall values, based on data from the recorded historical series from 1960 to 2017, show sharp fluctuations in precipitation (Figure 7). It is also observed that the monthly rainfall regime for Santa Filomena - PI is very complex, being very diversified seasonally, presenting great interannual and monthly variability.



Source: Medeiros (2022)

Figure 7 Time distribution of linear regression of monthly rainfall from January to December in the period from 1960 to 2017 for the municipality of Santa Filomena - PI

In accordance with the authors [103 and 94] the analysis of temporal trends allows detecting changes that some variables undergo over time, of anthropic origin or not.

It can be seen that in all the analyzed months the trend of regression is negative, meaning that each year the rainfall indices are reducing, and extreme events are being recorded more frequently, leaving the climate arid to semi-arid.

The months from November to April had the highest monthly averages of rainfall, ranging from 122.1 mm in November to 263.8 mm in February. Between May and September, the lowest monthly averages of rainfall are recorded, ranging from 0.3 mm in August to 48.4 mm in May, causing a strong local water deficit.

3.4. Monthly and annual future trend

Table 5 shows that the best coefficients for determining the regression (R2=0.3524 and 0.2605) for the months of February and March, the worst coefficient for determining the regression was for the month of September (R^2=0 .0002). Meaning that when the value is higher (R^2), it indicates the degree of approximation of the model to the averages, while when the value is lower (R^2) it indicates the degree of distance of the model from the averages.

Table 4 Linear equation, regression determination coefficient (R2), monthly historical average of precipitation from 1960 to 2017 in Santa Filomena - PI

Month	Linear equation	R^2	Average
January	Y= -2.9456x + 321.26	0.1509	234.4
February	Y= -4.5829x + 399.04	0.3524	263.8
March	Y= -3.8264x + 338.81	0.2605	225.9
April	Y= -2.9376x + 272.01	0.2069	185.3
May	Y= -0.5655x + 65.112	0.0279	48.4
June	Y= -0.1974x + 12.431	0.0461	6.6
July	Y= -0.0336x + 2.0768	0.0193	1.1
August	Y= -0.0087x + 0.5915	0.0118	0.3
September	Y= -0.0185x + 11.245	0.0002	10.7
October	Y= -0.8293x + 91.302	0.0471	66.8
November	Y= -1.6824x + 171.76	0.1252	122.1
December	Y= -2.7551x + 273.26	0.1478	192.0

Source: Medeiros (2022)

3.5. Annual rain index classification

The climate classification was performed according to the rainfall variability described in Table 6. This Table is used by the meteorology centers of the States and by the National Institute for Space Research (INPE) to carry out the monthly and annual classifications of the rainfall indices of each municipality of the NEB according to their variabilities in percentage deviations.

Table 5 Classification Criteria

Percentage deviation	Classification
±0,0 a 25,0%	Normal
±25,1 a 45,0%	Dry/Rainy
±45,1 a 70,0%	Very dry/Very rainy
±70,1 > 100,0%	Extremely dry/Extremely rainy

Source: Meteorology Centers and Center for Weather Forecasting and Climate Studies (CPTEC).

Table 6 shows the annual classification by the rainfall index for the years 1960 - 2017 for the area of the municipality of Santa Filomena - PI. During the period under study, there were twenty-eight (28) years with normal rainfall, ten (10) years classified as dry, eight (8) years classified as very dry. There were five (5) extremely rainy years, four (4) rainy years and two (2) very rainy years.

Table 6 Annual classification by the rainfall index for the years 1960 - 2017 for the area of the municipality of Santa Filomena-PI

Year	Classification	Year	Classification
1960	Normal	1989	Normal
1961	Normal	1990	Very dry
1962	Rainy	1991	Dry
1963	Normal	1992	Normal
1964	Normal	1993	Normal
1965	Normal	1994	Normal
1966	Very rainy	1995	Normal
1967	Normal	1996	Normal
1968	Normal	1997	Normal
1969	Extremely rainy	1998	Dry
1970	Normal	1999	Normal
1971	Very rainy	2000	Normal
1972	Rainy	2001	Dry
1973	Extremely rainy	2002	Normal
1974	Extremely rainy	2003	Dry
1975	Extremely rainy	2004	Dry
1976	Normal	2005	Very dry
1977	Normal	2006	Normal
1978	Dry	2007	Very dry
1979	Rainy	2008	Dry
1980	Normal	2009	Normal
1981	Rainy	2010	Normal
1982	Normal	2011	Dry
1983	Normal	2012	Very dry
1984	Dry	2013	Very dry
1985	Extremely rainy	2014	Very dry
1986	Dry	2015	Very dry
1987	Normal	2016	Very dry
1988	Normal	2017	Very dry

Source: Medeiros (2022).

3.6. Moving averages of precipitation

An average, as the name implies, shows the average value of a sample of given data. An arithmetic moving average is an extension of this concept, representing the average value over a period of time [76].

$$\text{Média móvel} = V_1 + V_2 + ... + V_n / N$$

Where;
V represents the different data,
While N is the time window over which the average is constructed.

The N parameter is very important when working with moving averages in graphical analysis, as it is a variable that we will adjust for better results. The moving average calculation time window is the parameter to be adjusted in search of better results. As in most technical analysis tools, there is no exact rule for sizing the average, but it is necessary to seek the balance and target operating time. This balance is important because:

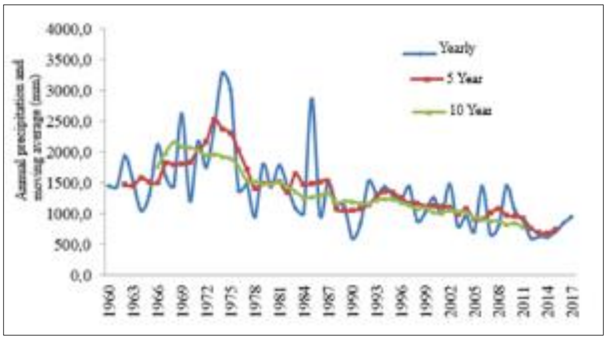
The longer the period, the smoother the behavior of the average and the more immune to noise and short movements (peaks) it will be. However, if it is too large, it may respond slowly to significant series changes.

The shorter the period, the closer to the mean the series data will follow. However, if the period is too small, the average will be excessively exposed to variations, losing its usefulness as a trend follower.

So how to find out which average to operate with? Working and using the technique of trial and error. Vary the value and see if the indicator response was higher or lower than in the previous test.

[28] in an attempt to study fluviometric variations in the São Francisco River applied moving averages to the river discharge index to the Morpará data.

Figure 8 shows the distribution of annual average precipitation and its moving average for 5 and 10 years for the municipal area of Santa Filomena - PI in the period 1960 - 2017. The behavior of observed precipitation follows the estimates of the moving average for 5 and 10 years, the rhythm of precipitation observed with reduction in amplitude and flattening between years. The estimates of the 10-year moving averages present values of greater significance than the 5-year ones. Similar studies were carried out by [38] on the precipitation of the São Francisco River, which corroborates the study.



Source: Medeiros (2022).

Figure 8 Distribution of average annual precipitation and its moving averages for 5 and 10 years for the municipal area of Santa Filomena - PI in the period 1960 - 2017

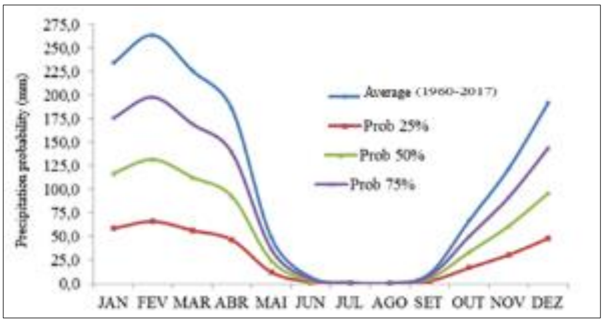
3.6.1. Probability of 25%, 50% and 75% precipitation occurrence

Knowing the probabilities of rain is of paramount importance in agricultural planning, enabling planting at the right time, planning irrigation, application of fertilizers and pesticides, and the use of agricultural machinery, etc. It is through operational agrometeorology that estimation values can be obtained that will allow decision making, such as soil preparation, sowing, pruning, harvesting, spraying and for water storage and its distribution in irrigation and harvest according to statement of [21].

Studies of probability distribution function fits or probability estimates using theoretical probability distribution functions in relation to a set of climatic elements have been developed, emphasizing the benefits in planning activities that minimize climatic risks. Among these we can mention the rainfall [8, 9; 13; 19; 18 and 20].

In figure 9. Probability distribution of average annual precipitation for the municipal area of Santa Filomena - PI in the period 1960 - 2017.

The probabilities of rain at 25%, 50% and 75% show that the months of June to September have the lowest rainfall and between the months of November to April the highest rainfall rates. With a probability level of 25% and 50% of rainfall, agriculture, supply and water damming must have adequate planning for their subsistence.



Source: Medeiros (2022).

Figure 9 Probability distribution of average annual precipitation for the municipal area of Santa Filomena - PI in the period 1960 - 2017

Table 7 shows the statistical variability with a 25% probability of precipitation in the municipality of Santa Filomena - PI. The expected annual maximum and minimum values are 822.5 mm and 149.6 mm respectively, the mean and median will be 339.4 mm and 280.4 mm, the median being the most representative of occurrence in the respective values, the standard deviation may present values above or below the average over time, between the months of May and September the coefficient of variance are statistically insignificant for its development.

Table 7 Statistical variability with 25% probability of precipitation in the municipality of Santa Filomena - PI

Variability of parameters (mm)						
Months	**Maximum**	**Minimum**	**Median**	**Mean**	**Standard Deviation**	**Coefficient of Variance**
January	142.4	17.6	45.4	58.6	32.0	0.546
February	161.5	16.3	53.8	66.0	32.6	0.494
March	159.3	0.0	78.3	56.5	31.7	0.560
April	153.0	0.0	35.7	46.3	27.3	0.588
May	73.1	0.0	0.5	12.1	14.3	1.180
June	21.0	0.0	0.0	1.7	3.9	2.349
July	7.6	0.0	0.0	0.3	1.0	3.752
August	2.5	0.0	0.0	0.1	0.3	4.006
September	26.6	0.0	0.0	2.7	5.4	2.023
October	78.8	0.0	9.7	16.7	16.1	0.966
November	102.7	0.0	23.7	30.5	20.1	0.658
December	184.3	0.0	33.3	48.0	30.3	0.630
Annual	822.5	149.6	280.4	339.4	149.5	0.441

Source: Medeiros (2022).

[15] report that the use of probability functions is directly linked to the nature of the data to which it relates; it is possible to estimate, through rainfall data series, the calculations of probability of precipitation, an important tool for planning agricultural operations, water damming and human consumption.

Table 8 shows the probabilistic fluctuations of precipitation with 50% of occurrences occurring in the municipality of Santa Filomena - PI. The expected annual maximum and minimum values will be 1645 mm and 299.1 mm respectively, the mean and median will be 678.8 mm and 560.7 mm, the median being the most representative of occurrence in the respective values, the standard deviation may present values above or below the average over time, between the months of May and September, the coefficient of variance is statistically insignificant for its development.

Table 8 Statistical variability with 50% probability of precipitation in the municipality of Santa Filomena - PI

Variability of parameters (mm)						
Months	**Maximum**	**Minimum**	**Median**	**Mean**	**Standard Deviation**	**Coefficient of Variance**
January	284.8	35.3	90.8	117.2	64.0	0.546
February	323.0	32.5	107.6	131.9	65.2	0.494
March	318.6	0.0	156.6	113.0	63.3	0.560
April	306.0	0.0	71.5	92.7	54.5	0.588
May	146.2	0.0	1.0	24.2	28.6	1.180
June	42.0	0.0	0.0	3.3	7.8	2.349
July	15.2	0.0	0.0	0.5	2.0	3.752
August	5.0	0.0	0.0	0.2	0.7	4.006
September	53.3	0.0	0.0	5.3	10.8	2.023
October	157.6	0.0	19.4	33.4	32.3	0.966
November	205.4	0.0	47.4	61.1	40.2	0.658
December	368.5	0.0	66.6	96.0	60.5	0.630
Annual	1645.0	299.1	560.7	678.8	299.1	0.441

Source: Medeiros (2022)

Table 9 Statistical variability with 75% probability of precipitation in the municipality of Santa Filomena - PI

Variability of parameters (mm)						
Months	**Maximum**	**Minimum**	**Median**	**Mean**	**Standard deviation**	**Coefficient of Variance**
January	427.1	52.9	136.2	175.8	96.0	0.546
February	484.5	48.8	161.4	197.9	97.8	0.494
March	477.8	0.0	234.8	169.4	95.0	0.560
April	458.9	0.0	107.2	139.0	81.8	0.588
May	219.2	0.0	1.5	36.3	42.8	1.180
June	62.9	0.0	0.0	5.0	11.6	2.349
July	22.7	0.0	0.0	0.8	3.1	3.752
August	7.5	0.0	0.0	0.3	1.0	4.006
September	79.9	0.0	0.0	8.0	16.2	2.023
October	236.4	0.0	29.0	50.1	48.4	0.966
November	308.1	0.0	71.0	91.6	60.2	0.658
December	552.8	0.0	99.9	144.0	90.8	0.630
Annual	2467.5	448.7	841.1	1018.2	448.6	0.441

Source: Medeiros (2022).

[110] states that the rains, considered a natural phenomenon, associated with the pattern of irregular urban occupation have caused damages and losses, which generate environmental, material and human dimensions, some identifiable and subject to evaluation and others subjective and incalculable.

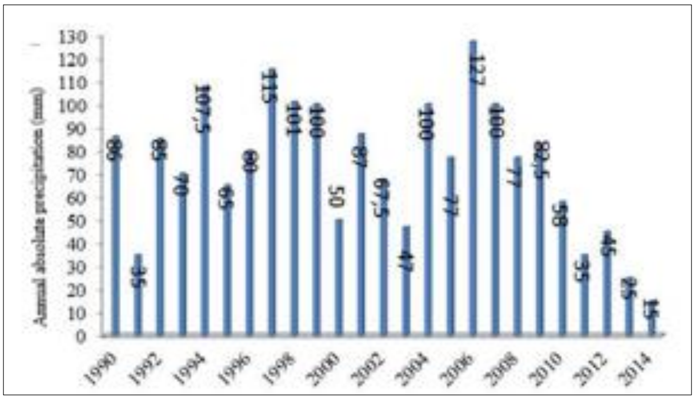
The measures of central tendency calculated for the studied area show monthly values: arithmetic mean (1018.2 mm), median (841.1 mm), standard deviation of (448.6 mm) with annual coefficient of variance of 44.1% , the absolute maximum values were recorded with greater intensities in the months corresponding to the rainy season, the absolute minimum recorded has oscillations and depends on the meteorological factors acting in the dry period that caused occurrences of extreme and isolated rains of strong magnitudes. The median is the most likely value of occurrence, except for the months of May to September, in accordance with the probability distribution of rain at 75%. (Table 10).

3.6.2. Extreme precipitation events

It is essential to have information related to climatic variables in the planning of water and soil use, such as heavy rains. According to [69], the analysis of heavy rainfall is based on one of the most applied products of hydrology. The analysis of its impacts is of crucial importance for society, since it identifies areas of risk for human occupation, among many other aspects elementary to basic sanitation [68].

The analysis of extreme events was only carried out for the period 1990 - 2014 due to the availability of daily rainfall data. The diagnosis of extreme precipitation events from 1990 to 2014 for the municipality of Santa Filomena - Piauí (Figure 10) shows that in the 1990s there was greater variability with precipitation rates ranging from 35 mm to 115 mm, with emphasis on the years of 1994, 1997, 1998 and 1999 that the pluviometric indexes were greater than 60 mm. From the 2000s onwards, variability in the intensification of maximum annual precipitation was recorded, with greater numbers of events with rainfall levels equal to or greater than 100 mm, in 2004 with 100 mm, 2006 with 127 mm and 2007 with 100 mm. In recent years (2010 to 2014) extreme events have fluctuated in space-time with maximum daily precipitation ranging from 14 to 35 mm.

It was observed that there was no direct relationship between the intensification of precipitation and occurrences of ENSO events (Figure 8). However, in a few years the relationship was established. In general, in the northeast, ENSO changes the total rainfall in the region and also the occurrence of dry periods in accordance with [19]. Extreme precipitation events are more evident between the months of the rainy season that extends from October to March, (Table 7) with sixteen (16) occurrences, out of a total of twenty-four (24), representing 66.6% of chances of occurrence. During this period, the most intense events with values greater than 100 mm were recorded (1994; 1997; 1998; 2003; 2006 and 2007). The dry season (April - September) showed 15 occurrences of extreme precipitation events, thus representing a 33.4% chance of occurrence. However, most of these events had precipitation values lower than 15 mm. These events, despite not being so frequent, have a large amount of water that is enough to cause great damage and local damage.



Source: Medeiros (2022)

Figure 10 Maximum annual rainfall (mm) during the period from 1990 to 2014 in Santa Filomena, PI

The characterization of the temporal variability of intense rainfall throughout its duration is essential to adequately quantify the effects caused by surface runoff in urban and rural areas as stated [104], being used in studies relevant to the design of hydraulic projects, such as works for the control in agricultural and urban areas and the storage and supply of water, both for irrigation, industry, domestic supply, and for animal survival in accordance with the authors [89 and 73].

Intense or extreme rainfall, also commonly known as maximum rainfall, is characterized by having an irregular distribution both temporally and spatially [7]. These have a large precipitated depth, which exceeds a minimum value, depending on a time interval [106].

In comparison, [114] carried out a study of the maximum annual daily precipitation in the city of Uberaba - MG and their results corroborated those of this study. [17] when evaluating the maximum annual daily rainfall in the municipality of Formiga - MG, observed that the Gumbel model for maximum rainfall rates best represented the data for this location, as occurred in this study.

Table 10 Day of occurrence of maximum annual precipitation during the period from 1970 to 2014 in Santa Filomena - PI

Year	Day/Month/Index	Year	Day/Month/Index	Year	Day/Month/Index
1990	08/nov 86,0	2000	18/fev 50,0	2010	27/jan 58,0
1991	25/out 35,0	2001	01/mar 87,0	2011	25/fev 35,0
1992	29/nov 85,0	2002	03/jan 67,5	2012	08/mar 45,0
1993	14/dez 70,0	2003	20/fev 47,0	2013	05/nov 25,0
1994	05/jan 107,5	2004	10/jan 100,0	2014	09/set 15,0
1995	30/nov 65,0	2005	01/jan 77,0		
1996	16/out 80,0	2006	11/mar 127,0		
1997	19/out 115,0	2007	30/nov 100,0		
1998	16/jan 101,0	2008	02/dez 77,0		
1999	20/nov 100,0	2009	14/mar 82,5		

Source: Medeiros (2022).

There is no study on the action procedure of large-scale El Niño/La Niña phenomena in the pluviometric regime, taking into account the number of days with occurrences of rain (NDCC) for the state of Piauí. An analysis was carried out to assess the presence of the phenomena, which would be of fundamental diagnosis for the local climate. Since understanding the rainfall regime of a given region can bring significant benefits to the agricultural, energy, water, agribusiness sector and especially in situations where water availability is not abundant most of the time.

In years of El Niño occurrence, approximately 52% of the precipitation values of Mossoró (RS) were below the historical average. Regarding the years in which the La Niña phenomenon occurred, rainfall was above average in 46% according to [83].

On a global scale, greater control is due to the climate variability mode called El Niño-Southern Oscillation (ENSO) in its different phases/intensities of the El Niño or La Niña phenomena, which are strongly included with changes in atmospheric circulation configurations, and with the ocean-atmosphere interaction in the Pacific and Atlantic [50, 52], and thus determining the anomalies of air temperature and mainly of rainfall in several regions [41, 40 and 78].

Table 12 shows the study period (1963 – 2017), the El Niño and La Niña classification and their intensity – Southern Oscillation, which fluctuate between moderate to strong.

[66] analyzed the relationship between the number of days with rain and precipitation in the municipality of Bom Jesus - PI between the period 1960 - 2014 and its influences between the El Niño/La Niña phenomena. The analyzes carried out encompassed all months of the year, generating information that will serve as an indication for adequate use of water for agriculture, irrigation, energy generation, water and natural resources and urban/rural water supply and the local economy. The analysis of the data collection from 1960 to 2014 made it possible to conclude that: In years where rainfall was below average (984.8 mm), there was a better temporal distribution of rainfall, as opposed to when it rained above average. There was an increase in precipitation and in the number of days with rain in the 1st quarter of the year; while in the 2nd and 4th quarter there is a reduction both in precipitation and in the number of days of rain, the numbers of days with extreme rainfall that were above or below the average were not explicitly associated with the ENSO phenomenon.

Table 11 Period, Classification and Intensity of El Niño and La Niña – Southern Oscillation from 1960 to 2017

Period	Classification	Intensity	Period	Classification	Intensity
1963	El Niño	Weak	1964-1965	La Niña	Moderate
1965-1966	El Niño	Moderate	1970-1971	La Niña	Moderate
1968-1970	El Niño	Moderate	1973-1976	La Niña	Strong
1972-1973	El Niño	Strong	1983-1984	La Niña	Weak
1976-1977	El Niño	Weak	1984-1985	La Niña	Weak
1977-1978	El Niño	Weak	1988-1989	La Niña	Strong
1979-1980	El Niño	Weak	1995-1996	La Niña	Weak
1982-1983	El Niño	Strong	1998-2001	La Niña	Moderate
1986-1988	El Niño	Moderate	2009-2010	El Niño	Weak
1990-1993	El Niño	Strong	2009-2010	El Niño	Weak
1994-1995	El Niño	Moderate	2010-1011	El Niño	Weak
1997-1998	El Niño	Strong	2011-2012	El Niño	Moderate
2002-2003	El Niño	Moderate	2012-2013	El Niño	Moderate
2004-2005	El Niño	Strong	2013-2014	El Niño	Moderate
2004-2007	El Niño	Strong	2014-2015	La Niña	Weak
2006-2007	El Niño	Weak	2015-2016	El Niño	Strong
2007-2008	La Niña	Strong	2016-2017	El Niño	Weak

Source: Monthly Weather Review (2015).

[65] the occurrences of extreme precipitation events in Campina Grande were analyzed, with daily precipitation data covering the years 1970 - 2010, the extreme events analyzed were the ones with the highest intensity of daily precipitation for the years studied. The results showed that there was a change in the behavior of precipitation occurrences from the 70's in the study area. There was an intensification in the maximum precipitation, presenting a greater number of events with precipitation values greater than 80 mm. In general, there was no direct relationship between the intensification of precipitation and occurrences of ENSO events. Extreme events were evident between the rainy season months, with 88% of occurrences and 12% in the dry season.

3.7. Days with rain occurrence

[60] analyzed the contribution to the capture of rainwater in relation to the number of days with occurrence of rain (dcc) and precipitation in the municipality of Teresina, PI to generate information that can serve as an indication for an adequate use of water from the rain. The average data showed annual precipitation equal to 1.337.8 mm in 80 days. The months that presented the highest total precipitation values were February, March and April, whose total rainfall was 860.5 mm distributed in just 46 days over the three months. The August, September and October quarters are the least rainy, with 60.6 mm in 12 days. In years with below-average rainfall, there was a better temporal distribution of rainfall, unlike when it rained above average, in which precipitation was more concentrated in time. There was a significant trend towards an increase in precipitation and in the number of days with rain in the 1st quarter of the year, while in the 2nd and 4th quarter this trend is inverse, that is, a reduction in both precipitation and the number of days of rain, when the period from 1913 to 2005 was considered, thus helping rainwater catchers to better plan their capture.

Table 12 shows the variability of rainy days recorded in the municipality of Santa Filomena between the period from 1991 to 2010.

The variability of days with annual rainfall ranges from 93 days in the year 1995 to 28 days in 2010. This information (-) no rainfall/no information

Table 12 Days with occurrences of rain in the period from 1991 to 2010 in Santa Filomena – PI

MONTHS/YEARS	JAN	FEV	MAR	ABP	MAY	JUN	JUL	AGO	SEP	OUT	NOV	DE	ANUAL
1991	-	-	-	-	-	-	-	-	-	-	-	-	-
1992	20,0	12,0	3,0	6,0	2,0	0,0	0,0	0,0	1,0	4,0	11,0	13,0	72,0
1993	8,0	16,0	11,0	8,0	2,0	0,0	0,0	0,0	7,0	6,0	6,0	12,0	76,0
1994	10,0	22,0	17,0	9,0	1,0	1,0	0,0	0,0	0,0	5,0	14,0	7,0	86,0
1995	9,0	14,0	15,0	13,0	10,0	0,0	0,0	0,0	0,0	3,0	15,0	14,0	93,0
1996	12,0	13,0	15,0	12,0	2,0	0,0	0,0	0,0	0,0	4,0	8,0	8,0	74,0
1997	19,0	11,0	17,0	9,0	1,0	0,0	0,0	0,0	0,0	6,0	6,0	13,0	82,0
1998	12,0	9,0	11,0	4,0	0,0	0,0	0,0	0,0	0,0	6,0	13,0	10,0	65,0
1999	17,0	10,0	-	5,0	1,0	0,0	0,0	0,0	0,0	0,0	-	17,0	50,0
2000	16,0	16,0	11,0	12,0	-	-	-	-	-	-	-	-	55,0
2001	-	-	-	-	-	-	-	-	-	-	-	-	-
2002	22,0	12,0	9,0	6,0	0,0	0,0	0,0	0,0	2,0	2,0	8,0	16,0	77,0
2003	15,0	12,0	16,0	4,0	0,0	0,0	0,0	0,0	0,0	1,0	0,0	0,0	48,0
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	-	-	-	-	-	-	-	-	-	-	-	-	-
2006	-	-	-	-	-	-	-	-	-	-	-	-	-
2007	12,0	15,0	0,0	0,0	1,0	0,0	0,0	0,0	0,0	0,0	4,0	0,0	32,0
2008	12,0	24,0	4,0	7,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	-	47,0
2009	13,0	8,0	-	19,0	10,0	0,0	0,0	0,0	4,0	14,0	7,0	14,0	89,0
2010	6,0	6,0	4,0	10,0	2,0	-	-	-	-	-	-	-	28,0
MÉDIA	10,8	10,1	7,8	5,5	1,3	0,1	0,0	0,0	0,6	2,5	5,7	7,3	47,6

OBS.: (-) No occurrences of rain/no information; Source: Medeiros (2022).

3.8. Evapotranspiration

The climate is formed by several elements, such as solar radiation, precipitation, air temperature, air humidity, wind (intensity and predominant direction), atmospheric pressure, evaporation, evapotranspiration, among others, where it is important to analyze their action in the environment. Variability is one of the best known elements of climate dynamics, and the impact produced by this variability, even within the expected range, can have significant repercussions on human activities as stated by [79].

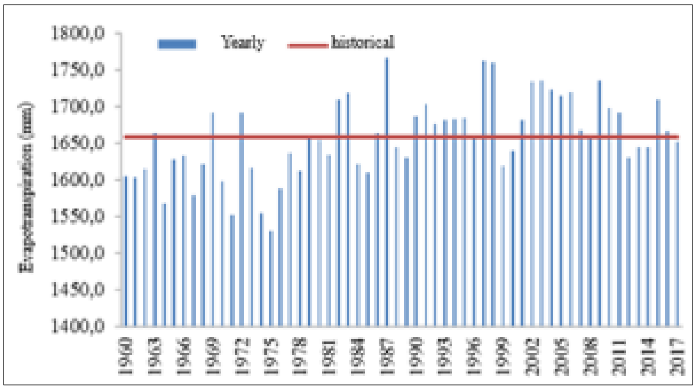
The term Evapotranspiration was defined by [115] as the loss of water from an extensive vegetated surface, with low growth, in an active development phase and without water limitation. According to [82], evapotranspiration is controlled by energy availability, atmospheric demand and soil water supply to plants.

Terrestrial evapotranspiration is one of the most important components of the hydrological cycle, affecting the water balance on the Earth's surface. It is also one of the meteorological variables that is widely applied to decision making in hydrology, agroecology, irrigation and other related areas, as stated by [37 and 88]. Results demonstrate that the magnitude of evapotranspiration trends are determining factors, which vary greatly from region to region. Additional studies on evapotranspiration and records in different regions of tropical countries is undoubtedly useful to provide more evidence and better understand the variability and trend of global evapotranspiration.

Potential evapotranspiration (ETP) is the phenomenon associated with the simultaneous loss of water from the soil through evaporation and from the plant through transpiration. The ETP estimate shows the maximum possible water loss to occur in a vegetated community. It means the maximum demand for water by the crop and becomes the reference for maximum replacement of water for the crop, whether through irrigation or rainfall according to Barros et al. (2012).

In accordance with [67] empirical or semi-empirical methods are the most used in estimating reference evapotranspiration, as they use readily available meteorological data. However, these methods were developed under specific climatic conditions, therefore, there is a need to test them in a certain region, by comparing the estimated values with the values measured in standard equipment. In this way, the most appropriate methods for the region are obtained, which can be used in other climatologically similar regions.

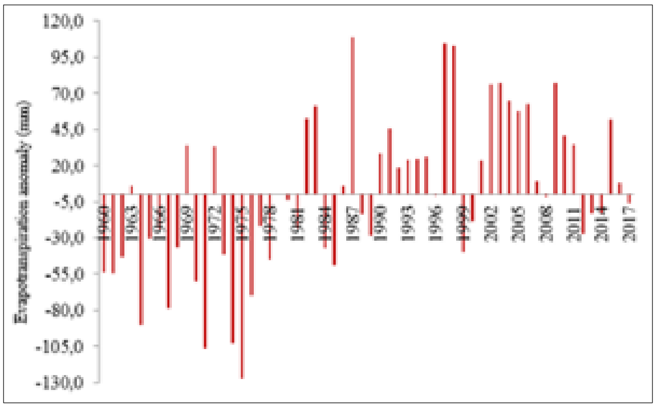
Figure 11 shows the annual and historical evapotranspiration distribution fluctuations for the municipal area of Santa Filomena - PI in the period from 1960 to 2017. Between the years 1960 to 1990, the evapotranspiration rates were below the historical average, except for the years of 1969, 1973, 1982, 1983, 1987, which evapotranspired above normal. In the period from 1991 to 2017, most of the evapotranspirative power flowed above average, meaning that it rained and was quickly evapotranspired, leaving the plantations in the stress range or wilting point, as well as influencing the water tables of the study area.



Source: Medeiros (2022).

Figure 11 Annual and historical evapotranspiration distribution for the municipal area of Santa Filomena - PI in the period 1960 - 2017

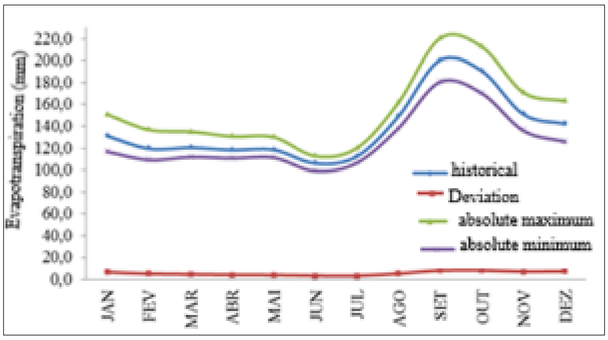
The annual evapotranspiration anomalies are represented in figure 12 with negative and positive fluctuations between the period from 1960 to 2017. In the period from 1960 to 1981 negative anomalies were recorded except for isolated years such as: 1969, 1972, 1982 and 1993 that had anomalies positive anomalies, from 1984 to 2017, ten years were recorded with negative anomalies, as follows: 1984, 1985, 1988, 1989, 1999, 2000, 2012, 2013, 2014 and 2017. Other years presented positive anomalies with fluctuations from 10 mm to 100 mm.



Source: Medeiros (2022).

Figure 12 Distribution of the annual evapotranspiration anomaly for the municipal area of Santa Filomena - PI in the period 1960 - 2017

The distribution of monthly evapotranspiration and its absolute maximum and minimum values and standard deviation for the municipal area of Santa Filomena - PI in the period 1960 - 2017 can be seen in figure 13, absolute maximum and minimum evapotranspiration elements followed by their average. In the months of May to July, the minimum peaks of the evapotranspiration element are registered, in the months of February to April there are gradual reductions. The standard deviation ranged from 3.3 mm in July to 8.3 mm in October.



Source: Medeiros (2022)

Figure 13 Distribution of monthly evapotranspiration and its absolute maximum and minimum values and standard deviation for the municipal area of Santa Filomena - PI in the period 1960 - 2017

[59], found in a study of climatic aptitude through the water balance according to [115 and 116], that evapotranspiration behaved similarly to rainfall, and when there was a higher rate of precipitation, there was also an increase in evapotranspiration rates. These results are in agreement with several studies carried out for the northeastern semi-arid region, as stated [42 and 59], which corroborate in the present study with the values of the studied area.

Table 13 shows the statistical variability of the absolute maximum and minimum potential evapotranspiration parameter, median, mean, standard deviation and coefficient of variance for the studied area for the period 1960 - 2017.

Analyzing the aforementioned parameters (Table 14) we emphasize that the median values are more likely to occur than the mean, the deviation values may have a reduction or increase variability in the mean values, the variance coefficients are not significant for the months of May to September. The maximum and minimum values may be repeated over the next five to ten years.

Table 13 Statistical variability of the potential evapotranspiration parameter in the municipality of Santa Filomena – PI

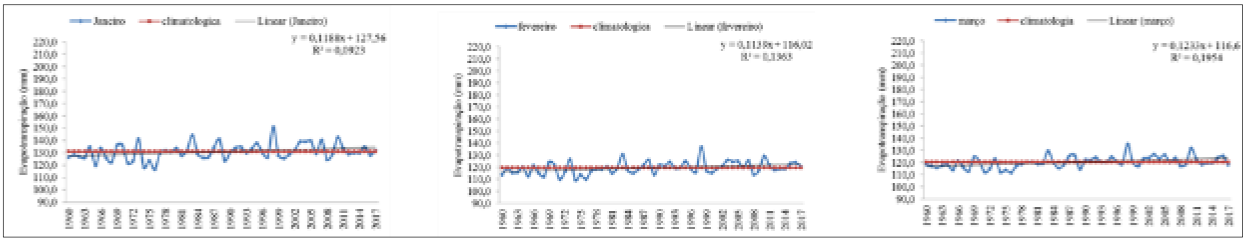
Variability of parameters (mm)						
Months	**Maximum**	**Minimum**	**Median**	**Mean**	**Standard deviation**	**Coefficient of Variance**
January	150.8	116.6	123.8	131.1	6.6	0.050
February	136.7	109.2	113.6	119.4	5.2	0.044
March	135.0	111.7	114.6	120.2	4.7	0.039
April	130.6	110.6	114.4	118.2	4.2	0.035
May	130.0	111.2	115.6	118.4	4.0	0.034
June	112.7	99.0	103.6	106.0	3.4	0.032
July	119.9	106.5	112.1	112.3	3.3	0.029
August	161.5	138.0	148.8	148.8	5.3	0.036
September	220.2	180.4	200.0	200.1	8.2	0.041
October	212.6	170.1	190.2	190.4	8.3	0.044
November	170.9	135.8	150.8	150.9	7.2	0.048
December	163.1	125.7	142.1	142.0	7.5	0.053
Annual	1766.6	1530.5	1629.7	1657.9	54.1	0.033

Source: Medeiros (2022).

3.9. Analysis of evapotranspirations distribution on monthly scale

Figure 14 shows the variability of the temporal distribution of linear regression and climatologies of monthly evapotranspirations from January to December in the period from 1960 to 2017, with the equation of the line and the values of R^2 for the area under study.

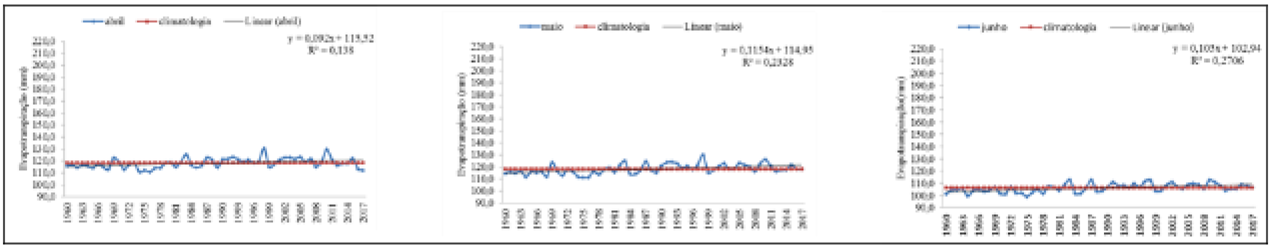
From January to March, positive trends are observed, that is, meaning gradual increases in evaporative power. In the period from 1960 to 1982, the evaporative indices flowed below or close to the climatological mean, except for the years 1970, 1971 and 1974, which flowed above. Between 2000 and 2017, evaporative irregularities were recorded due to fluctuations in meso and large-scale atmospheric factors acting in the region.



Source: Medeiros (2022)

Figure 14 a Time distribution of linear regression of monthly evapotranspirations from January to March in the period from 1960 to 2017 for the municipality of Santa Filomena - PI

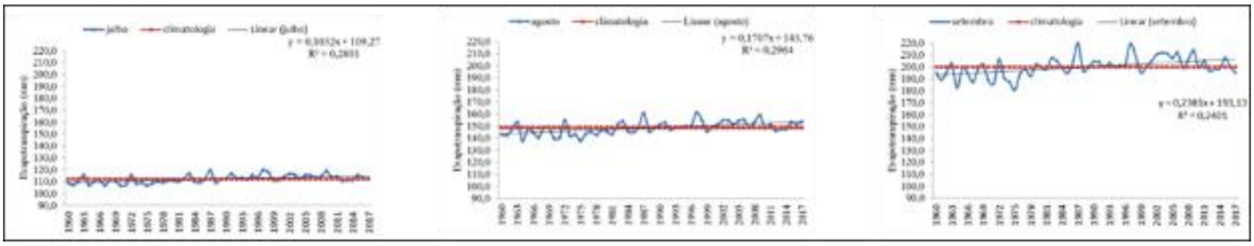
In the months of April and May prevail the evaporative indices of the same characteristics registered in the months of January to March. The month of June shows reductions in rainfall due to the fact that the soil is already out of field capacity and the dry period of the studied area begins.



Source: Medeiros (2022)

Figure 14 b Time distribution of linear regression of monthly evapotranspirations from April to May in the period from 1960 to 2017 for the municipality of Santa Filomena - PI

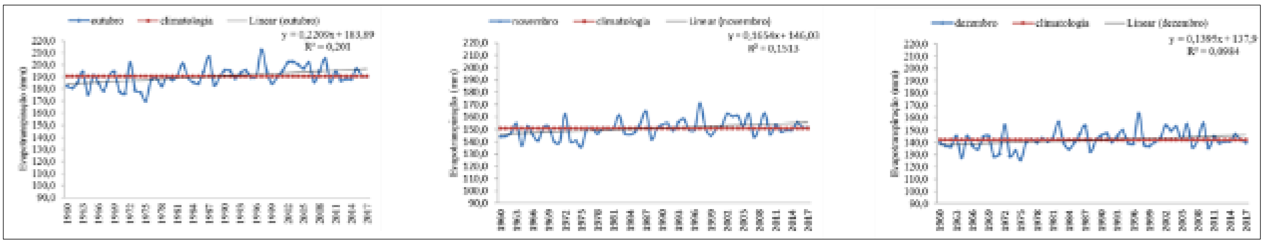
June, August and September are characterized by the hottest months where evapotranspiration rates reach their maximum, these increases in evaporative rates are directly linked to fluctuations in air temperature and to local and regional factors such as fire outbreaks and burning for land preparation, lack of mulch on the ground among others as the effects caused by man.



Source: Medeiros (2022).

Figure 14 c Time distribution of linear regression of monthly evapotranspirations from June, August to September in the period from 1960 to 2017 for the municipality of Santa Filomena - PI

The months of October, November and December are characterized by pre-season rains, the beginning and regularization of the rainy season. With evaporative rates ranging from 170.1 mm to 212.6 mm (October), 135.8 mm to 170.9 mm (November and 125.7 mm to 163.1 mm in the month of December.



Source: Medeiros (2022).

Figure 14 d Time distribution of linear regression of monthly evapotranspirations from October, November to December in the period from 1960 to 2017 for the municipality of Santa Filomena - PI

Table 14 shows the linear equations, regression determination coefficient (R2), monthly historical average of evapotranspiration from 1960 to 2017 in Santa Filomena - PI. It is observed that the best coefficients for determining the regression (R2=0.2801 and 0.2964) for the months of July and August, the worst coefficients for determining the regression were for the months of December (R2 = 0.0984) and January (R2 = 0.0923). Meaning that when the value is higher (R2), it indicates the degree of approximation of the model to the averages, while when the value is lower (R2) it indicates the degree of distance of the model from the averages.

Table 14 Linear equation, regression determination coefficient (R2), monthly historical average of evapotranspiration from 1960 to 2017 in Santa Filomena - PI

Months	Linear equation	R^2	Average
January	Y= 0.1188x + 127.56	0.0923	131.1
February	Y= 0.1139x + 116.02	0.1363	119.4
March	Y= 0.1233x + 116.6	0.1954	120.2
April	Y = 0.092x + 115.22	0.1380	118.2
May	Y = 0.1154x + 114.95	0.2328	118.4
June	Y = 0.105x + 102.94	0.2706	106.0
July	Y = 0.1032x + 109.27	0.2801	112.3
August	Y = 0.1707x +143.76	0.2964	148.8
September	Y = 0.2381x + 193.13	0.2401	200.1
October	Y = 0.2209x +183.89	0.2010	190.4
November	Y = 0.1654x + 146.03	0.1513	150.9
December	Y = 0.1395x + 137.9	0.0984	142.0

Source: Medeiros (2022).

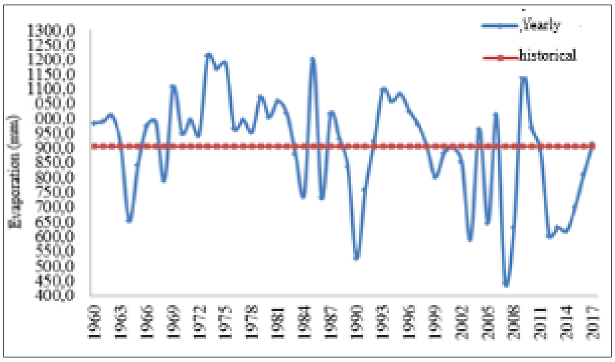
3.10. Evaporation

Understanding natural processes such as Evaporation (EVR) which is the process by which water changes from a liquid to a vapor state, and Evapotranspiration (EVT) which is the total amount of water lost to the atmosphere in areas where significant losses of water that occur through transpiration from plant surfaces and evaporation from the soil are extremely important, as they allow for more in-depth studies of these processes and others, such as real evapotranspiration (ETR), which constitutes the loss of water from a natural surface, in any condition, of humidity and vegetation cover, and Crop Evapotranspiration which according to [16] is a fundamental variable in the planning and execution of an irrigation management and essential in the determination of the water balance. The method proposed by FAO-56 [2] based on the product between the reference evapotranspiration, characteristic of each phenological stage of the crop. The study of all these processes aims to try to identify the periods of excess or scarcity of water and how each process behaves and thus seek to minimize the waste that occurs [53, 32 and 108].

Potential evaporation rates are stimulated by four meteorological variables (radiation, vapor pressure, wind speed and air temperature). Evaporation is a conceptual variable that cannot be measured directly [115 and 116]. Many different methods of estimating potential evaporation from one or more variables were developed according to local climatic conditions and availability of adequate data according to the authors Shuttleworth, (1993); Singh and Xu, (1997); Xu and Singh, (2000; 2001). [115 and 116] use a single air temperature variable that is related to the potential evaporative indices through empirical relationships. Being required to be recalibrated and to maintain accuracy when applied outside of the original spatial and temporal contexts (Xu and Singh, 2001).

[26] evaluated the variation of evaporation in the class "A" tank in the municipality of Teresina - PI in three and a half decades and made a comparison with the changes in urbanization that occurred in that period, finding changes in the evaporative indexes in face of the occupation of Man and their respective changes in space. The damming or blocking of the wind due to horizontal growth is contributing to the reduction of evaporation (EVR), the opposite occurs when it rains, there is no surface runoff and at the end of the precipitation evaporative indices occur in greater proportions due to the exchange of heat. The series of daily evaporation data used in this work was separated between periods, from 1986-1995, 1996-2005, 2006-2011 and compared with the complete series from 1976-2011, ending with a comparative analysis of the 35 years of data with the year 2011. There were fluctuations of lower and higher values that occurred, with emphasis on the decades 1976-1985 and 1986-1995, which showed the smallest variations. The decade of 2006-2011 in the month of October presented the biggest fluctuation of the studied periods. Annual fluctuations ranged from 1.852.7 to 2.409.4 mm. The evaporative indices had greater significance from the 1996s onwards, due to urban verticalization, alteration of the vegetation area, soil compaction with paving, backfilling of ponds and eutrophication of water mirrors. The study complemented findings made in which they conclude that expanding urban development patterns have a negative impact on regional vegetation cover and increase the frequency of extreme heat events, due to high rates of deforestation across the municipality.

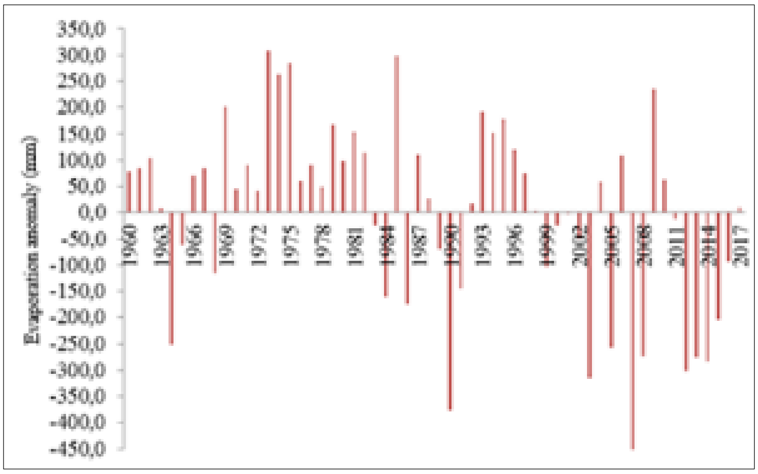
The distribution of annual and historical evaporation for the municipal area of Santa Filomena - PI in the period 1960 - 2017 is represented in figure 15. With an average of 904.5 mm with representation in the estimated fifty-eight (58) years thus distributed nineteen (19) years the evaporated index was below normality, seven (7) years the evaporated index equaled the average in thirty-two years the evaporative values exceeded the average. The years 1964, 1984, 1987, 1990, 2001, 2007 and 2011 stand out as the lowest evaporative indices and the years 1974, 1986 and 2010 as the years with the greatest evaporative powers.



Source: Medeiros (2022).

Figure 15 Annual and historical evaporation distribution for the municipal area of Santa Filomena - PI in the period 1960 - 2017

The oscillation of the annual evaporation anomalies is shown in figure 16. The anomalies fluctuations occurred between -461.7 mm to 308.7 mm. These anomalies may be related to the systems that cause or provoke rain in the region and at the meso and broad, regional and local scales, other relevant factors for the occurrence of these anomalies are the intensity of the wind, the incidence of solar radiation and the oscillation of temperature, donate.

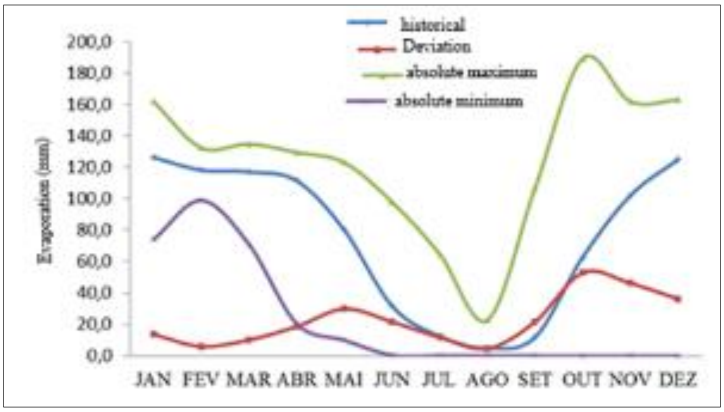


Source: Medeiros (2022)

Figure 16 Distribution of the annual evaporation anomaly for the municipal area of Santa Filomena-PI in the period 1960-2017

Evaporation, as well as evapotranspiration, adds up to accentuated water losses for the semi-arid areas of Brazil, being of great importance to identify the factors that affect the water balance of the region [117]. Tucci's study corroborates its development mainly in the last decade.

With a standard deviation ranging from 4.6 mm in the month of August to 56.9 mm in the month of October, demonstrating high variability in the evaporative power. The absolute minimum evaporative values occur between the months of January to July with fluctuations from 99 mm to 0.1 mm coinciding with the rainy months. The absolute maximum evaporated occurred in the months of October to January with oscillations from 162.1 mm to 189.5 mm. The average evaporation ranged from 4.7 mm in August to 126.4 mm in January with an evaporated rate of 904.5 mm, as shown in figure 17.



Source: Medeiros (2022)

Figure 17 A Distribution of monthly evaporation and its absolute maximum and minimum values and standard deviation for the municipal area of Santa Filomena - PI in the period 1960 - 2017

Table 15 shows the statistical variability of the meteorological element, maximum and absolute minimum evaporation, median, mean, standard deviation and coefficient of variance for the studied area for the period 1960 - 2017.

Between the months of January to June, anomalous values in the absolute minimums stand out. The maximum and minimum values may be repeated during the next five to ten years. The representativeness of the occurrence of median values is of high significance. The variability of the Variance Coefficient is not representative only in the month of September

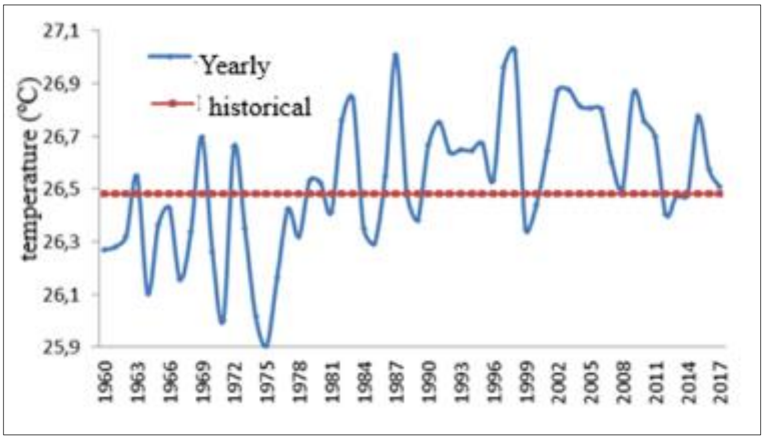
Table 15 Statistical variability of the evaporation parameter in the municipality of Santa Filomena – PI

Variability of parameters (mm)						
Months	**Maximum**	**Minimum**	**Median**	**Mean**	**Standard deviation**	**Variance Coefficient**
January	162.1	74.1	123.8	126.4	13.5	0.107
February	132.5	99.0	113.6	118.3	5.9	0.050
March	135.0	71.0	114.6	117.2	10.0	0.086
April	129.6	20.4	114.4	111.5	18.6	0.167
May	123.1	9.8	69.9	80.0	29.8	0.373
June	97.9	0.3	20.7	31.7	21.6	0.680
July	64.8	0.1	7.7	12.3	11.6	0.947
August	22.7	0.0	2.9	4.7	4.6	0.964
September	107.0	0.0	0.7	11.8	21.6	1.826
October	189.5	0.0	38.8	63.0	52.9	0.840
November	161.9	0.0	94.7	102.2	46.2	0.451
December	163.1	0.0	133.2	125.2	36.2	0.289
Annual	1213.4	442.8	835.0	904.5	176.8	0.195

Source: Medeiros (2022).

3.11. Observed trend in average air temperature

The variabilities and their oscillations of the annual average air temperature and its historical average for the municipal area of Santa Filomena - PI in the period 1960-2017 are shown in figure 17. Between the years 1960 to 1979 the average temperature flowed below the average history, except for the years 1969 and 1973. In the period from 1983 to 2017, an increase in the average temperature of 0.5 °C was recorded, except for the years 1986, 1989, 1999 and 2013. These oscillations are linked to regional and local systems and directly interconnected with human activities.

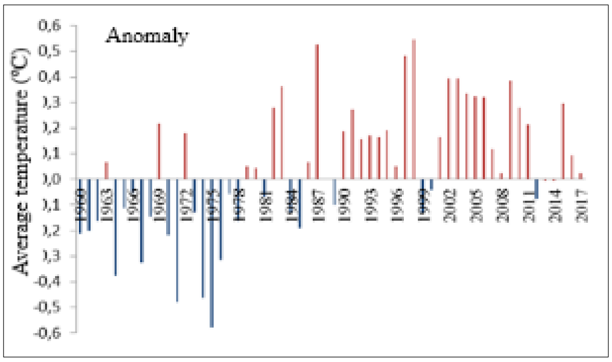


Source: Medeiros (2022).

Figure 17 B Distribution of the average annual air temperature and its historical average for the municipal area of Santa Filomena-PI in the period 1960-2017

Several researchers have demonstrated that in the first decade of the 21st century, they have reported strong indicators of climate trends, both on a global and regional scale. The authors' research [36 and 1], on a global scale, indicated an increase in the frequency of hot nights, a reduction in the amplitude of extreme temperatures, and also in the number of days with severe frosts. In South America, studies of extreme events through the analysis of trends in temperature indexes according to [119] indicated an increase in minimum temperature and hot nights, reduction of cold nights and thermal amplitude. The study by these researchers corroborates the study in progress for the Santa Filomena-PI area, where an increase in the minimum temperature and hot nights, and in the thermal amplitude already stands out.

Figure 18. Average annual air temperature anomaly for the municipal area of Santa Filomena-PI in the period 1960-2017. They demonstrate the variability of anomalies during the period 1960-1985 Santa Filomena maintained negative anomaly fluctuations (meaning it was colder) between -0.1 °C to -0.6 °C except for the years 1963, 1969, 1972, 1979, 1980, 1982 and 1983 that temperature inversion occurred (increase from 0.1 °C to 0.4 °C), this inversion is due to local and regional factors such as disproportionate deforestation, fires, fires and soil without vegetation cover.

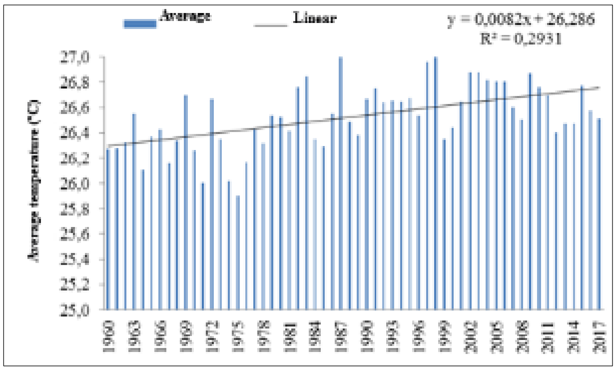


Source: Medeiros (2022).

Figure 18 Average annual air temperature anomaly for the municipal area of Santa Filomena-PI in the period 1960-2017

Between the years 1986-2017 the increase has been occurring on larger scales with fluctuations from 0.1 °C to 0.6 °C, these fluctuations in recent years are due to anthropogenic activities where man does not prevent soil, forests and water mirrors. The years 1989, 1999, 2000 and 2012 stand out in which the atmospheric systems acted and caused a reduction in the levels and/or levels of temperature.

Figure 19 shows the distribution of the average annual air temperature and its lineares trend for the municipal area of Santa Filomena-PI in the period 1960-2017. A positive angular coefficient line R^2 with moderate trend is observed, thus confirming mostly with statistically significant increases.

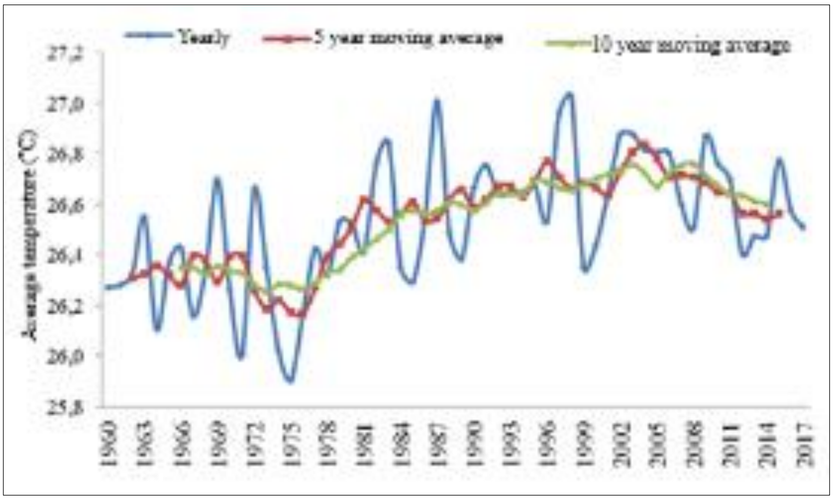


Source: Medeiros (2022).

Figure 19 Distribution of the average annual air temperature and its lineares trend for the municipal area of Santa Filomena-PI in the period 1960-2017

Scientists in the field of meteorology and the like, claim that observed climate trends, especially from the second half of the 20th century, have increased significantly. According to the Intergovernmental Panel on Climate Change (IPCC), these trends observed in the recent past are highly likely to continue in the same direction in the 21st century [44 and 45].

Figure 20 shows the variability of the annual average temperature distribution and its moving averages for 5 and 10 years for the area studied in the period 1960-2017.



Source: Medeiros (2022).

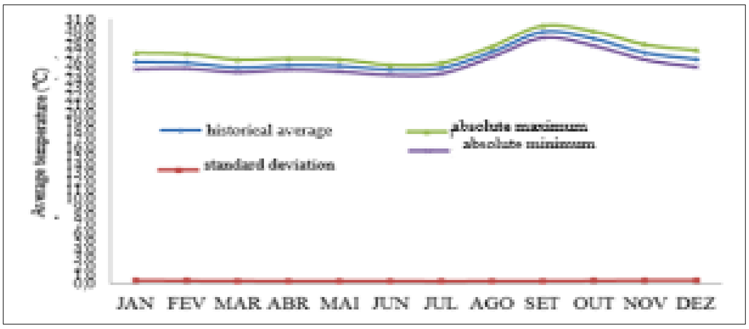
Figure 20 Distribution of the annual average temperature and its moving averages for 5 and 10 years for the municipal area of Santa Filomena-PI in the period 1960-2017

According to figure 21, the average temperature trend has greater significance for the ten-year variability, that is, in this time interval, significant increases in the analyzed parameter are expected, and its tendency and possible return after 10 years, so that this is going backwards, adaptation and awareness of the local and riverside population in the conservation of the environment and its surroundings are necessary.

The five-year moving average in some year intervals contributes to the average temperature trend has greater significance for the ten-year variability, that is, both the five-year and ten-year moving average bring us the possibility of increases.

The results of the present work coincide with studies by [93] which, despite showing a large number of stations with a strong tendency to increase in air temperature. Similar studies were carried out by [62] for the municipality of Cabaceiras - PB, which showed that R2 had low significance, but atmospheric conditions have been influencing these variability. [55] state that these fluctuations have great possibilities of being evidence.

Figure 18 shows the distribution of the average monthly air temperature and its absolute maximum and minimum values and the variability of the standard deviation for the municipal area of Santa Filomena-PI in the period 1960-2017.



Source: Medeiros (2022).

Figure 21 Distribution of the average monthly air temperature and its absolute maximum and minimum values and the standard deviation for the municipal area of Santa Filomena-PI in the period 1960-2017

The average air temperature oscillates between the minimum and maximum air temperatures, the minimum temperature being the one with the greatest tendency and stronger than the maximum temperature for the studied area. Nights are getting warmer between the months of July to January

The average temperature ranges from 25.1 °C in June to 29.5 °C in September, with an annual temperature of 26.5 °C. The warm quarter is centered on the months of August to November with oscillations from 27.1 °C to 29.5 °C. The cold quarter occurs between the months of March to June with an average temperature between 25.1 °C and 25.6 °C.

The fluctuations in absolute maximum temperatures range from 25.7 °C in the month of June to 30.3 °C in the month of September with the annual absolute maximum value of 27 °C. The absolute minimum average temperatures fluctuate between 24.5 °C in the month of June to 28.9 °C in the month of September. The variations of the standard deviations fluctuate in 0.3°C between the months of February to October and of 0.4°C registered in the months of November to January.

[27] in the analysis of the deviations of the annual average temperature, in relation to the average of the climatological series (1917 to 2006), they also found a trend of a significant increase in the average air temperature (0.8 ºC) in Passo Fundo, in the north of the state. Rio Grande do Sul. This study corroborates with the author demonstrating that the increase in the present work was more intense in the minimum than in the average.

Table 16 shows the statistical variability of the parameters of absolute maximum and minimum potential evapotranspiration, median, mean, standard deviation and coefficient of variance for the studied area for the period 1960 - 2017.

The coefficient of variances has low significance, the standard deviations indicate increases from 0.3 to 0.4 °C for the next periods, the median values have great possibilities of being more coherent than the average values, for the maximum and minimum values oscillations are expected greater than those recorded.

Table 16 Statistical variability of mean air temperature in the municipality of Santa Filomena – PI

Variability of parameters (mm)						
Months	**Maximum**	**Minimum**	**Median**	**Average**	**Standard deviation**	**Variance Coefficient**
January	27.1	25.2	26.6	26.0	0.4	0.015
February	27.0	25.2	26.3	25.9	0.3	0.013
March	26.3	24.8	25.7	25.4	0.3	0.012
April	26.4	25.1	25.8	25.6	0.3	0.011
May	26.3	24.9	25.5	25.5	0.3	0.012
June	25.7	24.5	25.0	25.1	0.3	0.012
July	25.9	24.6	25.2	25.3	0.3	0.011
August	27.9	26.6	27.1	27.2	0.3	0.011
September	30.3	28.9	29.5	29.5	0.3	0.010
October	29.6	27.9	28.5	28.7	0.3	0.012
November	28.1	26.3	26.7	27.1	0.4	0.014
December	27.4	25.4	25.9	26.3	0.4	0.015
Annual	27.0	25.9	26.5	26.5	0.3	0.010

Fonte: Medeiros (2022).

3.12. Aridity indexes and climate classifications and susceptibility level

The globally accepted characterizations of climatic definitions of regions are made by the Aridity Index (AI), which was created based on a methodology developed by [115]. This index measures the relationship between potential evapotranspiration, as defined by this author, and the total rainfall at a given location in a defined period of time according to [51]. Note the definition of semi-arid in the 1988 constitutional text:

“The concept of semiarid arises from a rule of the Brazilian Constitution of 1998, which in its Article 159 establishes the Constitutional Fund for Financing of the Northeast (FNE). The constitutional norm determines the application in the semiarid of 50% of the resources destined to the Fund. Law 7,827 of September 27, 1989 regulates the Federal Constitution, defining as semi-arid the region within the area of operation of SUDENE, with average annual rainfall equal to or less than 800 millimeters", according to the statement of [103].

In Brazil, the area's most susceptible to desertification are the states located in the Northeast region, characterized by low rainfall and high temperatures in the semi-arid climate. According to [97], in Brazil there are already four areas that stand out as centers of desertification, that is, the most intense areas affected by the process are Gilbués (PI), Irauçuba (CE), Seridó (PB) and Cabrobó (FOOT). In all these nuclei, human action – deforestation, livestock, extractivism – responsible for the removal of native vegetation (Caatinga) can be highlighted as the main triggering factor for the problem, leaving the bare soil exposed to accelerated erosion.

According to [51] this definition of semi-arid region takes into account only the amount of rainfall that falls during the year. No reference is made about the spatial and temporal distribution, which are also relevant problems associated with the rainfall distribution in the Northeast.

In this way, the way it is defined in the 1988 Constitution, the technical precept becomes subject to controversy, which defines the areas under that complex and fragile ecosystem based on criteria of water balance between the water that falls and that which is eliminated by evaporation and transpiration, especially from vegetables, as defined by the IA of [115].

The first criterion established by Interministerial Ordinance No. 1, of March 9, 2005, and which was published in the Federal Official Gazette on March 11, 2005, establishes rainfall below 800 millimeters. This criterion is absolutely unnecessary if the temporal distribution of rainfall is not established. If these 800 millimeters were distributed more evenly throughout the year, there could even be a possibility that the area, under these conditions, would not be characterized as semi-arid. On the other hand, an average above 800 millimeters per year can characterize a semi-arid climate, depending on the way it is distributed. The aridity index, which is the second criterion to be followed, o it is calculated taking into account the rainfall index, falls under the same question.

This same concern was raised by the Interministerial Working Group for the Redelimitation of the Northeastern Semi-Arid Region and the Drought Polygon defined by Interministerial Ordinance No. 2004, in its annex 2 when it discusses the delimitation of the semi-arid and dry sub-humid regions, according to the Convention to Combat Desertification. It is concluded that:

- Although the CCD establishes the criterion of the Aridity Index to delimit the area covered by the PAN, we understand that this should not be used in the proposal for delimiting the Semi-arid region, since according to this index, there is a significant reduction in the current semi-arid area of the FNE, which could generate political problems, since many of the current municipalities inserted in the semi-arid would no longer be, if this criterion were considered. In addition, potential evapotranspiration data are not very representative due to the historical series and the number of existing stations.
- Considering the great diversity of environments in the semiarid region, we understand that its delimitation should not be restricted to the criterion defined by Federal Law 7,827 of 1989, that is, an average annual isohyd of 800 mm, which has proved to be insufficient and of inadequate application. .
- Considering the existence of recent works, produced by Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) and Fundação Cearense de Meteorologia (FUNCEME), which, in addition to the rainfall criterion, also consider geoecological conditions, we suggest its use for the resizing of the semiarid. This is a criterion endowed with scientific rigor as it considers the interplay of mutual relationships between natural components, configuring a more reliable picture of the semi-arid northeastern environment. Based on the phytoecological conditions, it is assumed that vegetation is the best expression of climate as well as other geoenvironmental factors represented by relief, soils, lithology and hydrology (FUNCEME, 2004).

This conclusion was already accepted at the XXII Meeting of the Deliberative Council of SUDENE (Condel) held at the headquarters of Banco do Nordeste (BNB), in Fortaleza - CE, 11/23/2017, incorporating twenty-one (21) municipalities in the state of Piauí, including five (05) of these, belonging to the Gilbués Desertification Nucleus (Corrente, Riacho Frio, São Gonçalo do Gurguéia, Cristalândia do Piauí and Sebastião Barros). In this case, the presence of the caatinga biome and the Aridity Regime were taken into account, as well as the increase in vulnerability and poverty, a situation aggravated by the lack of food, water scarcity, degradation of natural resources, characteristics of areas susceptible to desertification.

These criteria are also listed here, as the municipalities of Gilbués, Monte Alegre do Piauí, Santa Filomena, Uruçuí and Barreiras do Piauí are part of the core area, being an extensive transition area from the cerrado to the caatinga.

The Aridity Regime is the other parameter that has been analyzed by the World Meteorological Organization (WMO), which tries to capture the interannual conditions, instead of focusing only on annual values of precipitation and evapotranspiration, which can mask the scarcity conditions, in a region or location. If a region and/or site has 7 to 8 months of rainfall less than half of the evapotranspiration, it is a semi-arid region. Following this reasoning and according to the rainfall data of the Santa Filomena region.

Table 17 Annual representation, aridity indices, level of susceptibility and climate classification for the area of the municipality of Santa Filomena-PI

Ano	ÍA	NS	CC	Ano	ÍA	NS	CC
1960	0.387	High	Semiarid	1990	0.687	Superior to Moderate	Sub-humid
1961	0.383	High	Semiarid	1991	0.555	Moderate	Dry sub-umid
1962	0.375	High	Semiarid	1992	0.450	High	Semiarid
1963	0.451	High	Semiarid	1993	0.349	High	Semiarid
1964	0.584	Moderate	Semiarid	1994	0.372	High	Semiarid
1965	0.482	High	Semiarid	1995	0.358	High	Semiarid
1966	0.403	High	Semiarid	1996	0.382	High	Semiarid
1967	0.374	High	Semiarid	1997	0.445	High	Semiarid
1968	0.513	Moderate	Dry sub-humid	1998	0.484	High	Semiarid
1969	0.346	High	Semiarid	1999	0.505	Moderate	Dry sub-humid
1970	0.406	High	Semiarid	2000	0.463	High	Semiarid
1971	0.359	High	Semiarid	2001	0.464	High	Semiarid
1972	0.441	High	Semiarid	2002	0.507	Moderate	dry sub-humid
1973	0.249	High	Semiarid	2003	0.660	Superior to Moderate	Semiarid
1974	0.249	High	Semiarid	2004	0.440	High	Semiarid
1975	0.223	High	Semiarid	2005	0.623	Superior to Moderate	Sub-humid
1976	0.393	High	Semiarid	2006	0.412	High	Semiarid
1977	0.392	High	Semiarid	2007	0.734	Superior to Moderate	Sub-humid
1978	0.409	High	Semiarid	2008	0.620	High	Sub-humid
1979	0.354	High	Semiarid	2009	0.344	High	Sub-humid
1980	0.394	High	Semiarid	2010	0.430	High	Sub-humid
1981	0.353	High	Semiarid	2011	0.473	High	Sub-humid
1982	0.405	High	Semiarid	2012	0.630	Moderate	Sub-humid
1983	0.488	High	Semiarid	2013	0.617	Moderate	Sub-humid
1984	0.541	Moderate	Dry sub-humid	2014	0.623	Moderate	Sub-humid
1985	0.253	High	Semiarid	2015	0.590	Moderate	Semiarid
1986	0.561	Moderate	Dry sub-humid	2016	0.513	Moderate	Semiarid
1987	0.426	High	Semiarid	2017	0.446	High	Semiarid
1988	0.434	High	Semiarid				

Legend: AI = Aridity indices; NS = Susceptibility Level; CC = Climate Classification; Source: Medeiros (2022).

The aridity index (Ia) is directly linked to the precipitation quotient and evapotranspiration. The Ia is dependent on the volume of rainwater and the respective loss generated by evaporation, transpiration or potential evapotranspiration. The Ia has been used to delimit areas susceptible to desertification worldwide. This index varies from 0.05 to 0.65, corresponding to very high and moderate susceptibilities respectively [98].

A study developed by [59] in the area of the Uruçuí Preto-PI river basin, corroborates the study of the Santa Filomena region. Also, [62] evaluated the water balance and the erosivity of the rains according to the climate change scenario for the municipality of Cabaceiras - PB, which indicate critical situations of soil conditions that will cause significant losses in erosivity and for water resources and rainfed crops.

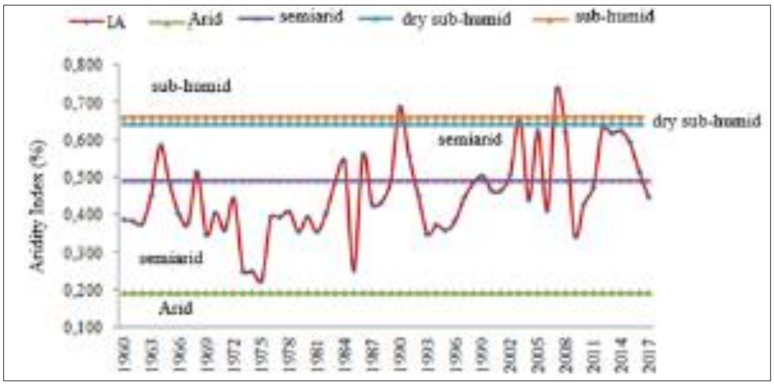
A reduction in the value of the aridity index means an increase in the trend towards desertification. This term has been defined by the United Nations (UN), since the 1980s, as "the degradation of land in arid, semi-arid and sub-humid and dry regions, resulting from several factors, including climatic variations and human activities". This situation leads to the reduction and destruction of the biotic potential of lands in accordance with [15].

Table 17 shows the period of years (1960-2017), aridity indices, climate classifications and the level of susceptibility for the municipal area of Santa Filomena. With the calculated AI, it was possible to classify the level of susceptibility to desertification, adapted from the classification (Table 12) proposed by [57].

In accordance with the proposal of [57] that used the IA values and according to Table 17 its is observed that in Santa Filomena - Piauí. Three levels of susceptibility (NS) and three types of climate classification (CC) were recorded. The interannual oscillations of the aridity indexes are highlighted, with three levels of susceptibility of the types high, moderate and superior to moderate and three types of climatic classification of the semi-arid, dry sub-humid and sub-humid types.

The performance of the calculation of the moving average of five and ten years for the annual precipitation and average air temperatures in order to provide more information about their variability. The moving average smoothes the variability of the data, indicating seasonality and trends, when they exist.

It can be observed in figure 22 the occurrence of Sub-humid, dry Sub-humid, semi-arid climate in the studied área, with high, moderate and superior susceptibility, moderate were those recorded for the period 1960-2017. The semi-arid climate prevailed in most municipalities in the studied área, with a susceptibility level ranging from high to moderate.



Source: Medeiros (2022).

Figure 22 Annual variability of the types of weather that occurred in the period 1960-2017 in the area of the municipality of Santa Filomena - PI

3.13. Erosivity factor

The impacts caused by water erosion are the impoverishment of the soil due to the loss of nutrients and organic matter, silting and contamination of water bodies by the displacement of fertilizers and pesticides, causing direct changes in the fauna and flora [14 and 84]. According to [84] soil erosion is analyzed as a process of natural origin with the purpose of landscape formation and soil renewal.

The need to obtain a methodology capable of evaluating the factors that cause water erosion and of estimating annual soil losses resulted in the development of the Universal Soil Loss Equation estimated by [122]. This equation is considered an instrument for predicting soil losses, requiring a relatively small amount of information when compared to more complex models and is well known and studied in Northeast Brazil (NEB). However, for its use, it is necessary to survey several factors, including the Rainfall Erosivity (R), which allows the evaluation of the erosive potential of precipitation in a given location.

Anthropogenic actions directly contribute to the advance of erosion with the removal of vegetation cover the soil loses its consistency, as the water, which was previously absorbed by the roots of plants, starts to infiltrate the soil, which can cause soil instability and erosion. The erosive process and its intensity depend mainly on the climatic conditions of the region, factors related to topography, soil cover and the properties of the same according to the statement by [39]. Rainfall erosivity is a function of its quantity, intensity and duration, according to comments by [51].

The R factor (rainfall erosivity) allows the assessment of the erosive potential of precipitation in a given location, making it possible to know the capacity and potential of rainfall to cause soil erosion, so that proper management and correct occupation of the same can be carried out [10 and 70].

The processes of surface erosion of soil particles are caused by the actions of wind and water, causing or causing wind or water erosion. Water erosion is the most important and worrying one due to the predominance of the tropical climate [14].

In the Brazilian Northeast most activities are based on the exploitation of natural resources, and in particular, on extractive vegetation cover, overgrazing of native areas and agricultural exploitation through often inadequate soil management practices [95].

Table 18 The results were performed through the development of the Universal Soil Loss Equation estimated by [122] and Smith (1958.1978) for the area of the municipality of Santa Filomena-PI in the period 1960-2017

ANO	JAN	FEV	MAR	ABR	MAI	JUN	JUL	AGO	SET	OUT	NOV	DEZ	anual
1960	930.2	1131.0	918.8	601.8	56.5	1.7	0.1	0.0	4.9	110.7	311.0	675.1	18443.8
1961	913.7	1107.7	901.8	592.9	57.4	1.9	0.1	0.0	5.2	110.9	307.0	665.5	18187.3
1962	1242.5	1939.1	1209.2	1031.2	130.6	7.0	0.3	0.0	3.5	161.1	209.7	2008.4	30044.7
1963	345.2	1496.9	1027.1	927.2	35.1	0.0	0.0	0.0	0.0	0.0	785.0	1067.6	19991.0
1964	1913.1	1633.9	27.1	4.2	0.0	0.0	0.0	0.0	0.0	31.9	176.0	364.8	10571.0
1965	281.5	2343.6	1044.9	612.8	14.2	0.0	0.0	0.0	0.0	41.5	150.1	322.8	15313.7
1966	890.9	3565.8	1393.9	4252.3	18.5	0.0	0.0	0.0	0.0	161.0	303.9	375.6	35037.7
1967	624.6	1948.9	703.2	844.2	39.3	0.0	0.0	0.0	33.1	101.0	460.0	1022.5	21913.4
1968	1039.0	1541.0	1265.8	1276.6	12.4	0.0	0.0	0.0	0.0	0.0	93.5	443.1	18469.5
1969	1509.2	3290.2	3017.6	1035.7	127.9	0.0	0.0	0.0	0.0	278.4	690.9	3888.0	50302.1
1970	2651.8	356.2	162.6	412.8	250.2	79.7	25.7	0.0	0.0	0.0	38.3	239.3	13485.3
1971	2849.3	2694.8	1596.6	1598.2	200.6	0.0	0.0	0.0	0.0	146.3	275.4	748.3	36514.2
1972	1040.3	1876.7	1025.8	1838.0	46.6	0.0	0.0	0.0	0.0	7.8	543.8	824.9	25571.3
1973	1355.3	1833.9	2045.9	1203.3	116.1	0.0	0.0	3.9	116.7	1376.8	932.2	1445.8	44095.1
1974	2052.9	4662.9	4554.2	1738.8	1211.1	72.1	0.0	0.0	0.0	1012.7	1153.9	1657.1	74215.8
1975	3369.2	3529.6	2308.5	1696.5	934.8	145.1	0.0	0.0	0.0	510.8	2159.9	805.8	64060.5
1976	667.7	1103.8	807.5	530.4	60.2	0.7	0.1	0.0	1.2	113.1	360.5	669.7	16831.1
1977	957.8	1170.6	926.9	621.3	58.0	1.8	0.1	0.0	4.9	113.1	320.4	693.3	18925.2
1978	348.4	336.3	334.1	278.1	97.8	10.7	1.1	0.2	19.0	117.2	163.2	324.2	9029.9
1979	1206.9	1844.3	1176.1	981.0	121.7	6.4	0.3	0.0	3.7	155.5	424.5	857.7	26541.7
1980	933.8	1107.0	899.1	593.8	57.8	2.0	0.1	0.0	4.9	109.9	304.6	650.6	18169.8

1981	1193.3	1805.7	1162.2	960.8	118.2	6.1	0.3	0.0	3.7	153.2	418.4	847.3	26113.8
1982	920.9	1124.8	908.6	602.0	58.8	2.0	0.1	0.0	5.1	112.0	307.0	665.5	18354.5
1983	582.3	635.4	1338.4	267.4	0.0	0.0	0.0	0.0	0.0	34.8	130.7	390.9	11269.4
1984	348.6	235.3	2139.4	523.7	25.3	0.0	0.0	0.0	0.0	0.0	17.3	237.1	9884.3
1985	3341.4	1375.3	2023.2	1589.5	30.5	21.1	0.3	0.0	180.8	559.0	647.3	5833.9	58748.1
1986	477.2	674.7	655.5	654.4	1.2	0.0	0.0	0.0	0.0	0.0	0.0	605.9	9517.6
1987	598.0	592.8	2991.0	559.0	1.2	0.0	0.0	0.0	0.0	199.9	387.4	558.0	19728.1
1988	919.0	551.4	1061.6	398.5	0.0	0.0	0.0	0.0	0.0	325.7	152.5	183.7	12851.2
1989	539.2	719.6	1361.2	358.8	0.3	0.0	0.0	0.0	0.0	38.9	178.3	318.4	11908.5
1990	117.5	1169.1	300.7	226.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4091.7
1991	521.2	688.6	356.6	24.8	0.0	0.0	0.0	0.0	0.0	0.3	205.6	482.0	7210.3
1992	3487.1	561.6	219.4	96.5	6.5	0.0	0.0	0.0	14.9	92.8	1412.6	640.8	20071.5
1993	107.9	1095.1	344.4	228.2	16.1	0.0	0.0	0.0	217.6	195.6	421.0	1601.3	15833.9
1994	334.0	1276.6	1026.5	648.9	1.0	0.3	0.0	0.0	0.0	389.6	599.1	516.2	18064.7
1995	221.1	361.8	367.8	423.3	197.2	0.0	0.0	0.0	0.0	157.4	1153.2	1054.9	15221.7
1996	536.2	405.2	579.7	646.2	143.9	0.0	0.0	0.0	0.0	91.6	486.8	484.4	13647.2
1997	1797.2	235.3	2170.6	276.1	5.7	0.0	0.0	0.0	0.0	128.2	365.6	551.4	18081.8
1998	297.5	287.7	363.9	8.2	0.0	0.0	0.0	0.0	0.0	217.6	503.9	571.9	7918.5
1999	701.5	523.7	631.0	203.9	12.7	0.0	0.0	0.0	0.0	0.0	125.4	857.0	10266.8
2000	1511.5	1038.3	317.5	715.6	60.2	0.0	0.0	0.0	1.7	22.9	133.8	389.6	14556.8
2001	688.6	759.9	315.9	197.6	146.9	0.0	0.0	0.0	3.9	52.2	160.4	198.6	9726.0
2002	3763.6	1078.3	533.7	143.9	0.0	0.0	0.0	0.0	43.0	7.3	145.4	814.7	19030.9
2003	982.8	361.3	1237.3	163.5	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0	6642.8
2004	351.3	335.5	336.6	282.1	99.7	11.1	1.1	0.2	19.7	122.5	169.6	336.3	9204.8
2005	1264.4	94.0	338.1	77.5	0.0	0.0	0.0	0.0	0.0	12.7	122.6	60.2	5433.3
2006	933.8	1107.0	899.1	593.8	57.8	2.0	0.1	0.0	4.9	109.9	304.6	650.6	18169.8
2007	453.4	2297.5	0.0	0.0	7.8	0.0	0.0	0.0	0.0	0.0	86.8	0.0	4923.5
2008	207.3	1866.6	154.3	295.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	189.0	6607.4
2009	344.4	257.2	101.3	1925.9	662.6	0.0	0.0	0.0	19.2	579.7	113.2	884.7	18311.9
2010	133.8	266.6	458.1	890.9	18.5	0.0	0.0	0.0	4.7	104.6	311.6	650.8	10625.7
2011	304.8	318.3	294.7	250.3	85.7	9.4	1.0	0.1	16.4	101.8	145.0	293.6	8075.7
2012	192.2	212.5	229.9	266.6	32.8	3.3	0.0	0.0	0.0	0.0	60.2	119.9	4148.8
2013	212.5	192.2	270.8	205.3	15.1	0.0	0.0	0.0	0.0	0.0	131.6	195.9	4462.3
2014	196.6	280.0	170.0	195.9	15.7	0.0	0.0	0.0	0.0	7.8	98.5	193.9	4348.4
2015	181.8	593.1	115.7	247.3	28.5	0.2	0.0	0.0	1.0	33.7	77.6	169.0	5351.5
2016	254.1	960.9	219.9	272.5	26.4	2.9	0.3	0.0	5.1	31.3	44.6	238.9	7326.4
2017	260.5	431.1	179.3	682.1	164.3	0.0	0.0	0.0	0.0	118.6	70.4	361.3	8889.6

Source: Medeiros (2022)

It emphasizes that the adoption of appropriate management techniques for pastures, the eradication of exposed soils and the rearrangement of temporary agriculture production sites would greatly mitigate the direct and indirect negative environmental impacts.

Table 19. There are the annual average values of rainfall and erosivity for the municipality of Santa Filomena - PI in the period 1960-2017. It is noteworthy that in the rainy season the erosive values are more intense than the values of the dry season. it should also be noted that the extreme events of moderate to heavy rainfall in short time intervals corroborate the increase in the rates of pluvial erosion.

Table 19 Annual mean values of rainfall and erosivity for the municipality of Santa Filomena - PI in the period 1960-2017

Years	**Precipitation (mm)**	**Erosivity (MJ.mm $ha^{-1}ano^{-1}$)**	**Years**	**Precipitation (mm)**	**Erosivity (MJ.mm $ha^{-1}ano^{-1}$)**
1960	1450.5	18443.8	1989	1121.4	11908.5
1961	1438.6	18187.3	1990	598.2	4091.7
1962	1932.8	30044.7	1991	834.8	7210.3
1963	1520.9	19991.0	1992	1524.5	20071.5
1964	1045.5	10571.0	1993	1326.0	15833.9
1965	1300.2	15313.7	1994	1432.9	18064.7
1966	2115.7	35037.7	1995	1295.6	15221.7
1967	1605.3	21913.4	1996	1215.0	13647.2
1968	1451.7	18469.5	1997	1433.7	18081.8
1969	2617.2	50302.1	1998	882.1	7918.5
1970	1206.5	13485.3	1999	1027.7	10266.8
1971	2167.7	36514.2	2000	1262.0	14556.8
1972	1757.9	25571.3	2001	995.5	9726.0
1973	2422.1	44095.1	2002	1477.5	19030.9
1974	3290.0	74215.8	2003	795.5	6642.8
1975	3017.2	64060.5	2004	963.8	9204.8
1976	1374.5	16831.1	2005	706.8	5433.3
1977	1472.7	18925.2	2006	1437.8	18169.8
1978	952.9	9029.9	2007	667.0	4923.5
1979	1796.8	26541.7	2008	793.0	6607.4
1980	1437.8	18169.8	2009	1444.4	18311.9
1981	1779.7	26113.8	2010	1048.7	10625.7
1982	1446.4	18354.5	2011	892.4	8075.7
1983	1085.6	11269.4	2012	603.1	4148.8
1984	1005.0	9884.3	2013	629.5	4462.3
1985	2867.4	58748.1	2014	620.0	4348.4
1986	982.9	9517.6	2015	700.5	5351.5
1987	1509.1	19728.1	2016	842.7	7326.4
1988	1172.8	12851.2	2017	944.2	8889.6
			total	78739.7	1060333.5

Source: Medeiros (2022).

The processes of surface erosion of soil particles are caused by the actions of wind or water, causing or causing wind or water erosion. Water erosion is the most important and worrying one due to the predominance of the tropical climate in accordance with [14].

[91 and 92] showed that the values obtained in studies that quantify soil losses for each specific characteristic of each of the factors can be used to support the classification of vulnerability. Studies such as the authors mentioned above collaborate with the current one.

3.13.1. Estimated annual land losses through the universal equation

According to the authors [86] and [24] land degradation is one of the serious local, regional and global environmental problems, where all forest ecosystems present considerable alterations of their originais áreas, mainly resulting from anthropic actions.

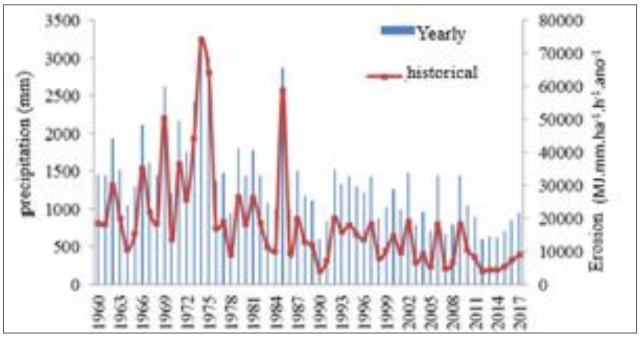
The need to obtain a methodology capable of evaluating the factors that cause water erosion and of estimating annual soil losses resulted in the development of the Universal Soil Loss Equation estimated by [122] and Smith (1958. 1978). This equation is considered a good instrument for predicting soil losses, requiring a relatively small amount of information when compared to more complex models and being well known and studied in Brazil. However.

, for its use, it is necessary to survey several factors, among them the Rainfall Erosivity (R), which allows the assessment of the erosive potential of precipitation in a given location.

The R factor (rainfall erosivity) allows the assessment of the erosive potential of rainfall in a given location, making it possible to know the capacity and potential of rain to cause soil erosion, so that proper management and correct occupation of the same can be carried out according to Authors' comments [10 and 70]. The calculation of this factor is the sum of the monthly erosivity values, according to the equation:

$$R = \sum_{1}^{12} EI_{30}$$

The fluctuations of annual precipitation versus erosivity of the period 1960-2017 in the area of the municipality of Santa Filomena - PI are shown in figure 23, the period from 1998 to 2017 stands out in which the erosive rates were lower than the rainfall incidences, this was due to that in the referred period, the rainy season was below the historical normals, softening the soil confrontation. The erosive irregularities between the years 1960 to 1997 were intense when compared to the period already mentioned.



Source: Medeiros (2022).

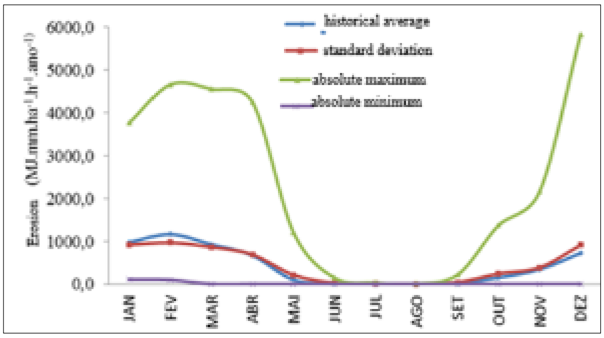
Figure 23 1960-2017 in the area of the municipality of Santa Filomena – PI

Source: Medeiros (2022).

Figure 24 Annual variability of erosivity in the period 1960-2017 in the area of the municipality of Santa Filomena – PI

Figure 24 shows the annual variability of erosivity in the period 1960-2017 in the area of the municipality of Santa Filomena - PI. In the period 1988 to 2017, erosivity flowed below normal, oscillating from 1000 to 10000 $MJ.mm.ha^{-1}.h^{-1}.year^{-1}$, thus being considered an atypical period due to rainfall irregularities recorded. In the period from 1960 to 1986, irregularities of high significance were observed in the erosion of the studied area.

The monthly erosivity oscillations and their absolute maximum and minimum values and the standard deviation for the municipal area of Santa Filomena-PI in the period 1960-2017 are represented in figure 25. February. May. October and December. The values of minimum erosivity are highlighted in the months of January and February, this reflects the anomalous incidence of precipitation for isolated years caused by rainfall that were characterized with irregular rains and their fluctuations were above average. The values of maximum and minimum erosibilities may be added to these values due to changes in weather and climate in the study area.



Source: Medeiros (2022).

Figure 25 Distribution of monthly erosivity and its absolute maximum and minimum values and standard deviation for the municipal area of Santa Filomena-PI in the period 1960-2017

Table 20 and figure 26 shows the monthly values of rainfall and erosion in the study area. These values correspond to the monthly averages of each elemento, with these calculations the erosive amount per month of the studied area is visible.

Table 20 Monthly average values of rainfall and erosivity for the municipality of Santa Filomena - PI in the period 1960-2017

Months	Precipitation	Erosion
January	234.4	972.4
February	263.8	1160.1
March	225.9	922.8
April	185.3	668.5
May	48.4	98.1
June	6.6	6.7
July	1.1	0.5
August	0.3	0.1
September	10.7	12.7
October	66.8	149.4
November	122.1	342.3
December	192.0	722.4
Annual	1357.6	18281.6

Source: Medeiros (2022).

Figure 26 The distribution of monthly rainfall and erosion for the municipal area of Santa Filomena-PI in the period 1960-2017. In all months the erosive variability exceeds the rainfall values

Water erosion is one of the main causes of soil degradation in the world with losses much higher than the natural replacement rates according to Needelman (2013). In Brazil, the acceleration of erosive processes, with the use of the soil by man. is responsible for the transport of soils. Seeds, fertilizers and pesticides to lakes, rivers and the ocean according to [6]. The consequences are loss of productivity, advance of agricultural frontierssilting and contamination of water bodies, in addition to loss of biodiversity. According to the authors mentioned above, the planning of agricultural activities, considering the vulnerabilities of the environment and the potential for use is essential to minimize its degradation. This is confirmed by the calculations made for the studied area.

According to [80] gully erosion is caused by several mechanisms that act on different temporal and spatial scales, and can be understood by the following processes: particle displacement, transport by diffuse surface runoff transport by concentrated flows, erosion by waterfalls undermining liquefaction mass movements and particle drag.

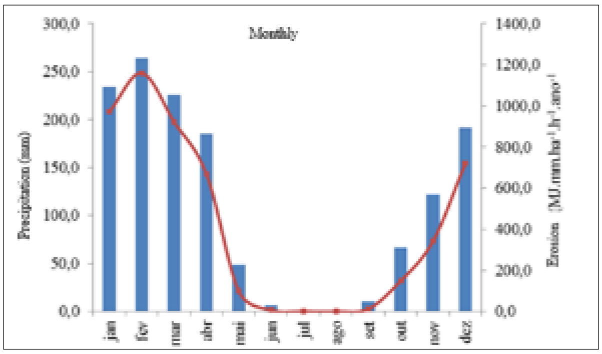


Figure 26 Distribution of monthly rainfall and erosion for the municipal area of Santa Filomena-PI in the period 1960-2017

3.13.2. Hydric balance

Climatological water balance (BHC) is the accounting of water inflows and outflows in the soil, and its interpretation provides information on the gain, loss and storage of water in the soil, [115] proposed the first roadmap for the elaboration of the water balance for climatic purposes. For the calculation. it was considered that all water entry into the soil was due to precipitation (P) and all output by potential evapotranspiration (EP), with the soil having the capacity to store 100 mm of available water, that is, the water between the field capacity (CC) and wilting point (PM). In 1955. [116] proposed a new roadmap for calculating the Water Balance, including some innovations:

- The demand for water by the atmosphere is given by ETp, and the response of the soil-plant system is given by the real evapotranspiration (ETr). In this case. a decrease in the ER/EP ratio is considered as the water content in the soil decreases, whereas in the 1948 method. ETr = ETp between field capacity and wilting point.
- The available water capacity in the soil started to vary depending on the crop with which it is working. For this case, the available water content in the soil between CC and PM at the depth of the soil where at least 80% of the root system of the crop is found (effective depth of the root system) is considered. It should be considered that, according to the texture of the soil. it will have a greater or lesser capacity to retain water, which will be compensated by the fact that the root system of plants exploits a greater volume of soil in sandy soils, which have less water holding capacity.

The climate is a set of physical, chemical and biological elements that characterize the atmosphere of a given place and influence the beings that are in it, as stated [83]. Therefore. it is considered one of the most important variables of the environment. However, human activities can contribute in negative ways, as they gradually change both human and animal living conditions, thus causing changes in the quality of life of society in general. The difference in thermal response between the urban and rural environment is mainly marked by the development of heat islands in urban areas in accordance with [87]. [81] clarifies that heat islands are the result of the physical properties of buildings and other structures. In addition, heat is emitted by human activities.

According to [100] they showed that the state of Piauí has different climatic conditions, with fluctuation in rainfall whose origin is very individualized, also presenting relatively variable annual average temperatures. The rainfall shows great spatial and temporal variability, showing two rainfall regimes: in the south of the state it rains from November to March and in the center and north the rainy season starts in December and lasts until May. The rainfall varies between 700 - 1.300 mm in the southern region, between 500 - 1.450 mm in the central region and between 800-1.680 mm in the north of the state. The authors also analyzed the municipal rainfall variability between the different rainfall regimes for the regions (North. Central and South regions), and proved that there are common areas of rainfall occurrences with their respective provoking and inhibiting systems. In the North region, rainfall rates are more evenly distributed than in the Central and South áreas, showing the physiographic aspects. Relief, fauna, flora and distance from the sea. Due to the great variation in rainfall over the years, they observed that macro, meso and microscale phenomena are of great importance for the state's rainfall regimes, which follow the chronological time of their activities and duration.

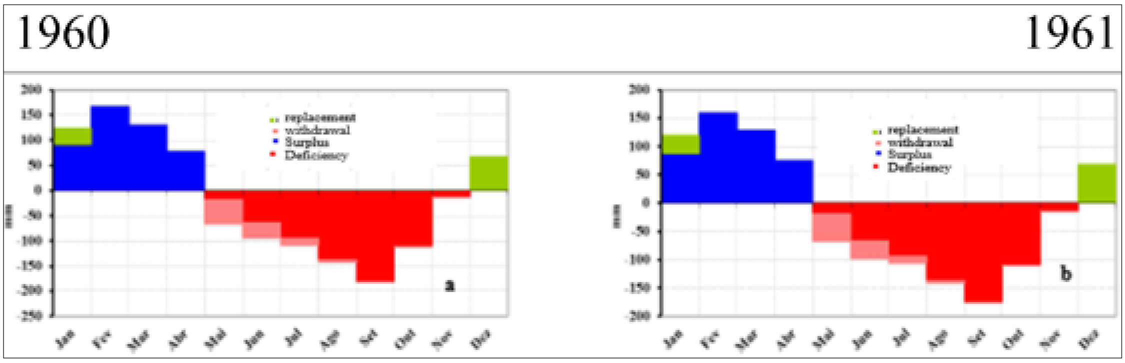
The result of the water balance was obtained through the climatological temperature and average precipitation of the municipal area for the field capacity of 100 mm.

Figures 27 (a. b) and Tables 11 and 12 shows the representations of the annual water balance of 1960 and 1961 for the municipal area of Santa Filomena-PI.

In the years of 1960 (Figure 27a) and 1961 (Figure 27b) there was water replacement in the soil in the months of December and January, the withdrawal of water was registered between the months of May and August, the deficiencies were between the months of hand to November and the months from January to April there were water surpluses. Rainfall reductions of 92.8 mm and 81 mm were recorded for the respective years.

In the year 1960 (Figure 27a) evapotranspiration was 1602.4 mm; evaporated 984.1 mm; with water deficiency of 620.2 registered between the months of May and November. The water surplus occurred between the months of January to April with an annual total of 466.5 mm.

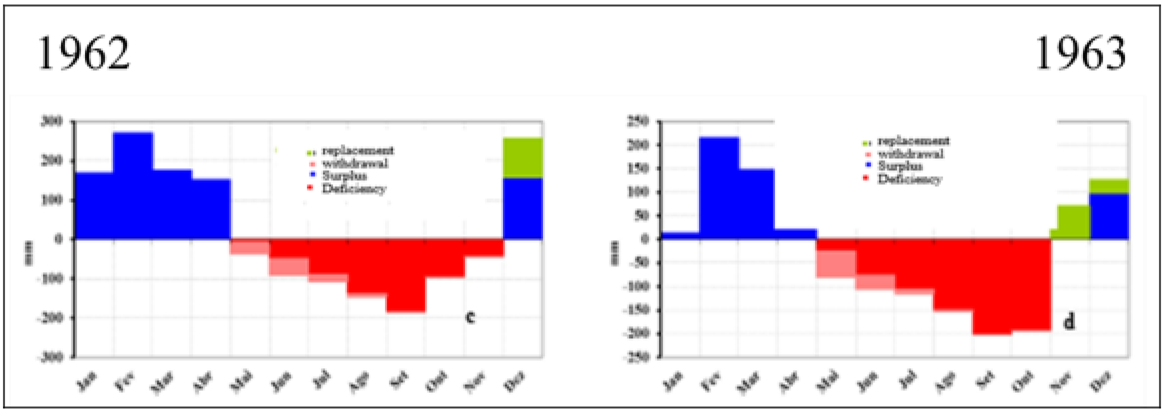
In 1961 (Figure 27b) the water deficit was 614.2 mm between May and November. The annual water surplus of 449.6 mm recorded between January and May. It evapotranspired 1603.2 mm and its annual evaporation was 989 mm.



Source: Medeiros (2022).

Figure 27 a Representatives of the annual water balance of 1960(a) and 1961(b) for the municipal area of Santa Filomena-PI

Figure 27(c.d) are the representations of the annual water balance for 1962 and 1963. In figure 26c corresponding to the year 1962. 1008.6 mm evaporated. 1614.4 mm evapotranspired, surpluses were recorded between the months of December to April with 924.2 mm/year, water deficits ranged from May to November with 605.7 mm/year.



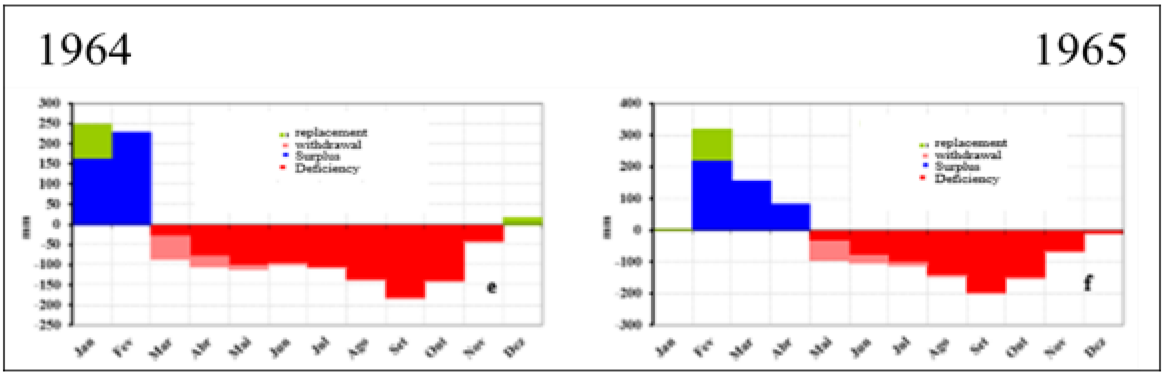
Source: Medeiros (2022).

Figure 27 b Representatives of the annual water balance of 1962(c) and 1963(d) for the municipal area of Santa Filomena-PI

Figure 27d (year 1963) there was a surplus in the months from December to April with an annual total of 608.9 mm. the month of January stands out, which was reduced due to the influence of the summer seasons (lack of rain during the rainy season), replacement was recorded in November and December, withdrawals were between the months of May and August, the deficiencies occurred between the months of May and October with an annual value of 751 mm.

Figures (27e. f) are the representations of the annual water balance for 1964 and 1965. Figure 26e (year 1964) recorded a surplus of 398.2 mm in the months of January and February, the replacement of water in the soil was between the months of December and January, the water withdrawal was between the months of February and November and of low intensity, because the soil had already dried. The deficiencies with high irregularity occurred between March and November, with an annual total of 915.1 mm.

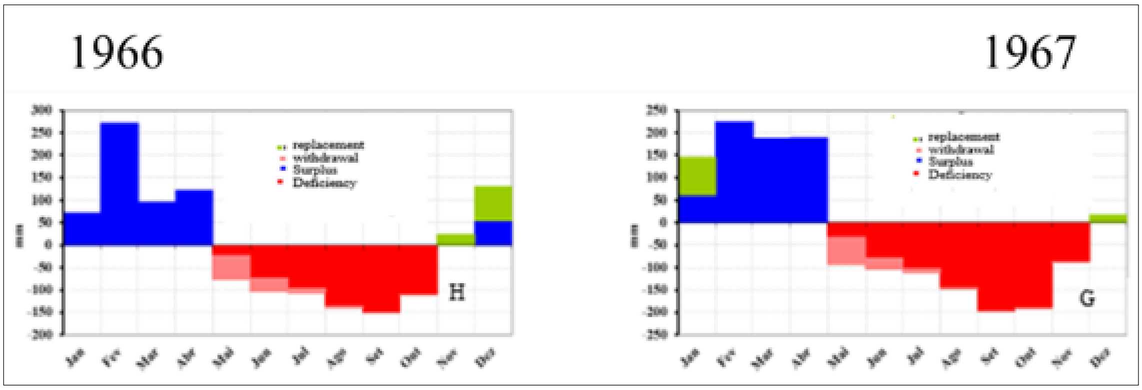
Medeiros (2014) showed that the spatial variation of meteorological variables. Water Deficiency (DEF). Water Surplus (EXC), Aridity Indexes (Ia), Humidity Indexes (Iu) and Water Indexes (Ih) as a function of water capacity available (CADs) at the levels of 75. 100. 126 and 150 mm. obtained through the climatological water balance proposed by [115 and 116] in Teresina - PI. Brazil. Through this analysis, it was verified that there were small oscillations in these variables as a function of the CAD's studied, proven by the space-time variability of the pluviometric índices, together with the high oscillation of the potential evapotranspiration. This work corroborates the current study.



Source: Medeiros (2022).

Figure 27 c Representatives of the annual water balance of 1964(e) and 1965(f) for the municipal area of Santa Filomena-PI

Figure (27f) corresponds to the graph of bH in the year 1965, there is water deficiency between the months of May to December with an annual total of 785.1 mm. the replacement of water was registered in the month of February and the withdrawal between the months of May to July. The surplus occurs between the months of February to April with an annual total of 485 mm. The month of January predominated an intense summer period lasting 30 days, in addition to the non-contribution of the factors that provoked the rainfall in the rainy season.



Source: Medeiros (2022).

Figure 27 d Representatives of the annual water balance of 1966(g) and 1967(h) for the municipal area of Santa Filomena-PI

Figures 27(g. h) represent the annual water balance graphs for 1966(g) and 1967(h). In 1966 (Figure 27g) the surpluses were between normal and occurred in the months of December to April with an annual total of 1141 mm. the replacement of water was between the months of November and December, the withdrawals of water in the soil registered- between May and July and water shortages predominated between May and October with an annual total of 658.7 mm.

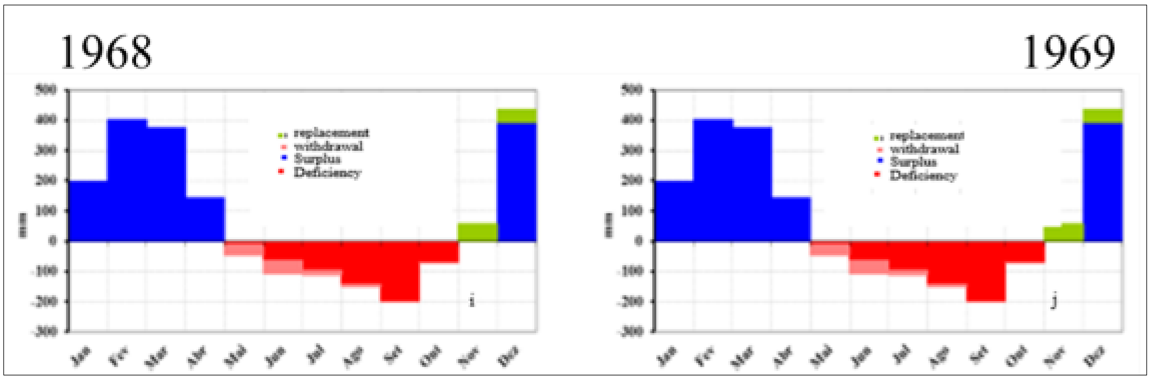
In figure (27h) corresponds to the year 1967, there is a small replacement of water in the months of December and January, the withdrawals occurred in the months of May to June. the annual water deficit recorded was 590.4 m Figure 27. Representatives of the annual water balance of 1964(e) and 1965(f) for the municipal area of Santa Filomena-PI.

Figure (27f) corresponds to the graph of bH in the year 1965, there is water deficiency between the months of May to December with an annual total of 785.1 mm. the replacement of water was registered in the month of February and the withdrawal between the months of May to July. The surplus occurs between the months of February to April with an annual total of 485 mm. The month of January predominated an intense summer period lasting 30 days, in addition to the non-contribution of the factors that provoked the rainfall in the rainy season.

Figures 27(g. h) represent the annual water balance graphs for 1966(g) and 1967(h). In 1966 (Figure 27g) the surpluses were between normal and occurred in the months of December to April with an annual total of 1141 mm. the replacement of water was between the months of November and December, the withdrawals of water in the soil registered- between May and July and water shortages predominated between May and October with an annual total of 658.7 mm.

m between the months of May to November. The rainy season started with deficiencies due to the blocking action in the rain-provoking systems. the surpluses were registered in the months from January to April totaling 616.5 mm.

In the year 1968 (Figure 27i) there were atmospheric blocks in the months of October and November and the summer period was activated. From December to April there was a surplus with an annual total of 662.4 mm. The water replacements occurred in the months of November and December and the withdrawal of water between the months of May and June the water deficiencies registered between the months of May and October with an annual total of 832.3 mm.



Source: Medeiros (2022).

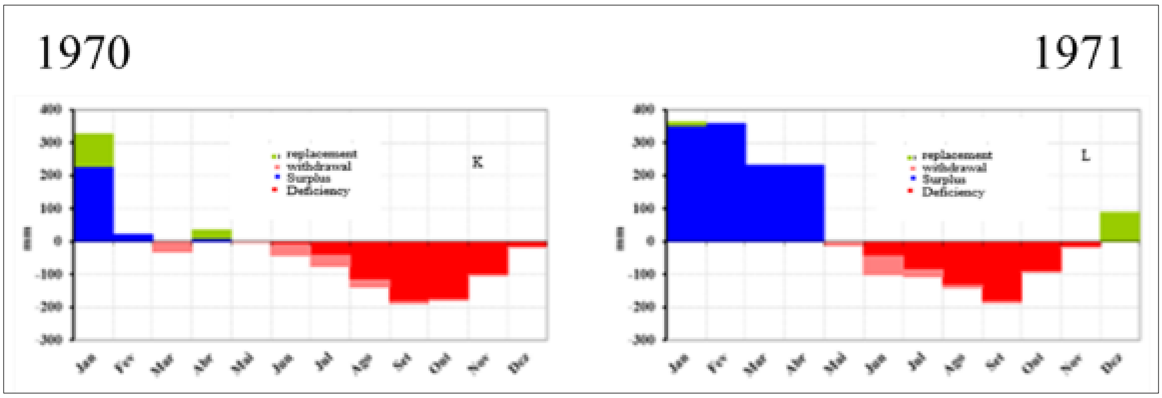
Figure 27 i Representatives of the annual water balance of 1968(i) and 1969(j) for the municipal area of Santa Filomena-PI

Figure (27j) has a lot of similarity with figure 27i. it differs from this one in the decimal values that were low in relation to the previous figure.

Figure (27k) (1970) with irregular and low-intensity rainy season causing surpluses between 20 mm and 210 mm in the months of January. February and April, the month of March predominated a period of strong atmospheric and summer blockage. There was water replacement in January and April, water withdrawal between June and August and water deficit from June to December, totaling 585.6 mm. A bad year for the agricultural sector and harmful in terms of erosion rates.

Figure (27l) (1971) there was atmospheric blockage from the pre-season to the month of December, thus reducing the incidence of rainfall. Small replacement of water occurred in December, the withdrawal of water in the soil was recorded in the months of May to August. The classification of the rainy season was a rainy year.

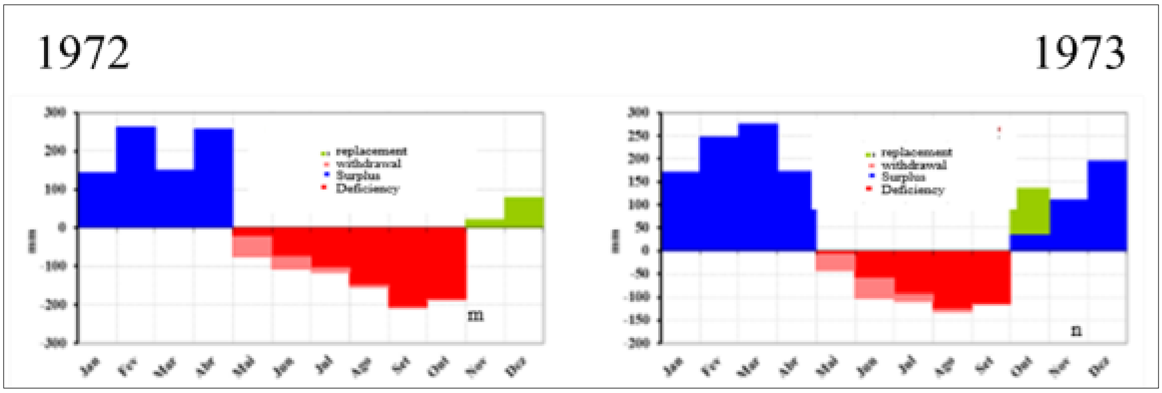
In figure (27m) there is the graph of BH demonstrating that in the months of January to April there was a surplus of water between normality, the rains were of moderate to strong intensity, the deficiencies occurred in the months of May to October, the removal of of water flowed between the months of May to July and replenishment of water in the soil in the months of November and December.



Source: Medeiros (2022)

Figure 27 f Representatives of the annual water balance of 1970(k) and 1971(l) for the municipal area of Santa Filomena-PI

In figure (27n) the BH is graphically accounted for with water surpluses recorded between the months of October to April, therefore being an extremely rainy year. The withdrawals and replacements of water in the soil occurred between May and June and in November, respectively. The deficiencies were between the months of May to September. Therefore the year 1973, considered an extremely rainy year.

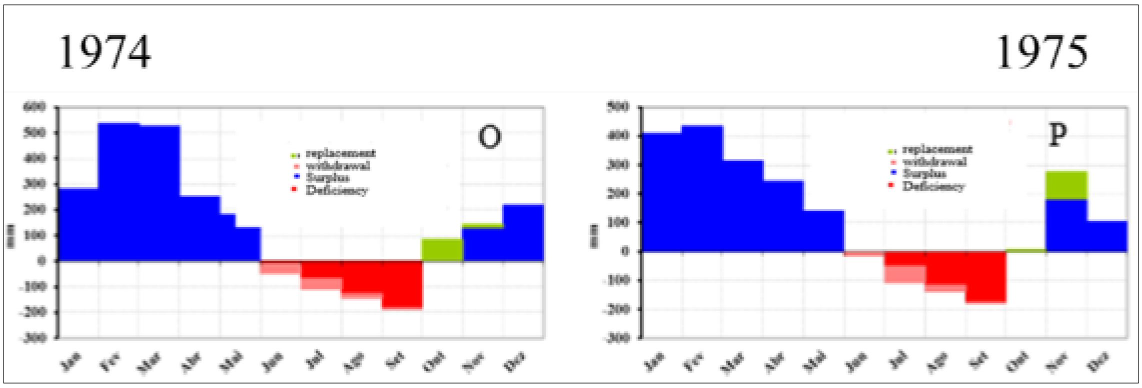


Source: Medeiros (2022)

Figure 27 m Representatives of the annual water balance of 1972(m) and 1973(n) for the municipal area of Santa Filomena-PI

Figure (26o) (1974) the surpluses were normalized within the expectation of the rainy season, considered an extremely rainy year. Water deficiencies were recorded from June to September, water replenishment in October and November and water withdrawal in June to August.

The year 1975 (Figure 27p) considered as a rainy year and its surpluses normally occurred during the rainy season, the deficiencies were between the months of June to September and the withdrawal of water in the soil between June and August while the replacement of water registered in the months of October and November.

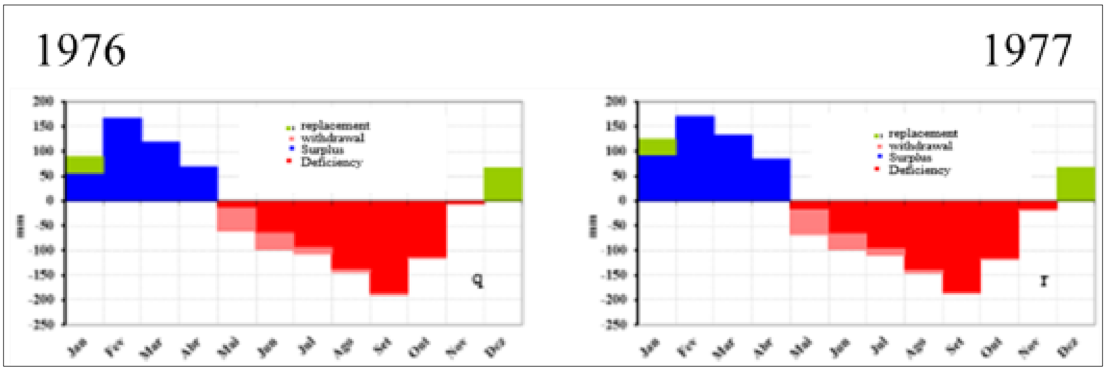


Source: Medeiros (2022).

Figures 27 h Representatives of the annual water balance of 1974(o) and 1975(p) for the municipal area of Santa Filomena-PI

Figure (27q) has the months from January to April with water surpluses, water shortages were between May and November, water replenishment took place between December and January and water withdrawals were between the months from May to July. The year was classified as rainy and with a strong performance of summers from October to December 1976.

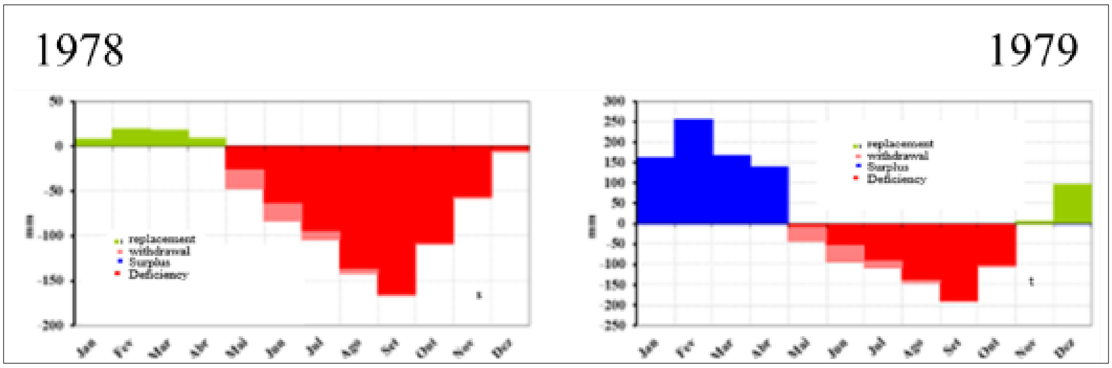
The year 1977 represented by figure (27r) had water surplus in the months from January to April, deficiencies between May to November, water replenishment in the months of December and January and withdrawal of water from May to August. The year was classified as rainy and with strong summer performances between the months of October and December.



Source: Medeiros (2022).

Figure 27 Representatives of the annual water balance of 1976(q) and 1977(r) for the municipal area of Santa Filomena-PI

The year 1978 classified as very dry (Figure 27s) did not present water surpluses, there was a replacement of water in the soil below the field capacity (CAD 100 mm). The withdrawals of water from the soil were registered between the months of May and August and the water shortages occurred between the months of May and December.

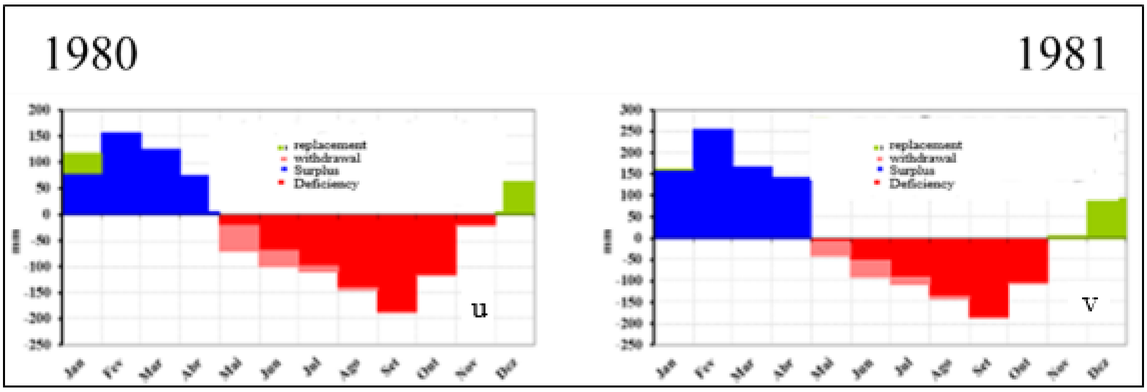


Source: Medeiros (2022).

Figure 27 Representatives of the annual water balance of 1978(s) and 1979(t) for the municipal area of Santa Filomena-PI

Figure (27t) corresponds to BH in 1979. With normal rainfall due to strong atmospheric blockages and intense summers. Surpluses occurred between January and April, water shortages from May to October, water withdrawal between May and August and water replacement in November and December.

The year 1980 (Figure 27u) presented water deficiencies from May to November, water withdrawal between May and August, water replacement between December and January and water surpluses occurred between January and April. Ranked with one year between normal rainfall.

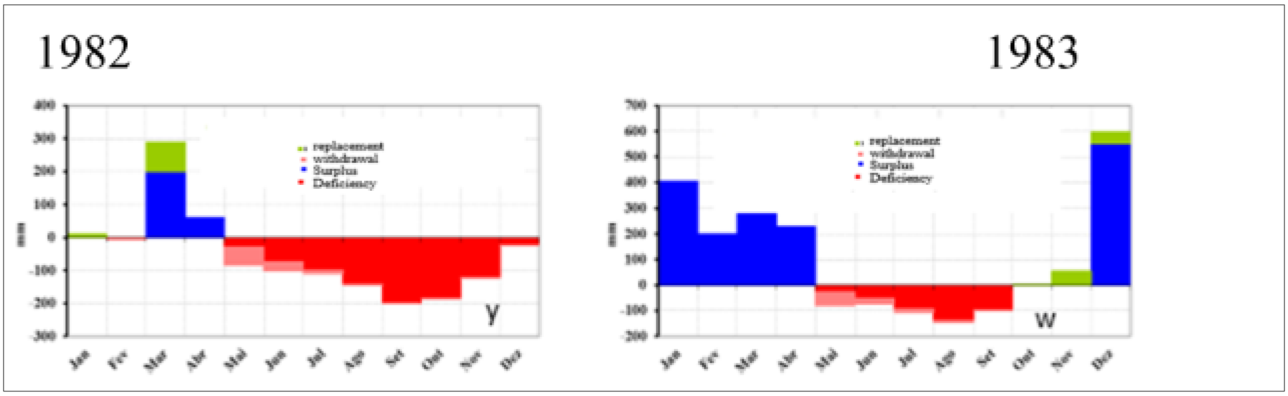


Source: Medeiros (2022).

Figure 27 Representatives of the annual water balance of 1980(u) and 1981(v) for the municipal area of Santa Filomena-PI

In figure (27u) there is water surplus between the months of January to April, replacement of water in the month of November and December, in the months of May to August there was a withdrawal of water, the water deficiencies between June and October. The year 1981 was classified as rainy.

1982 (Figure 27v) was a year of normal rainfall, with water shortages between May and November, withdrawal and replacement of water in the soil occurred between May and August and December and January. The water surplus was registered between the months of January to April.



Source: Medeiros (2022).

Figure 27 Representatives of the annual water balance of 1982(y) and 1983(w) for the municipal area of Santa Filomena-PI

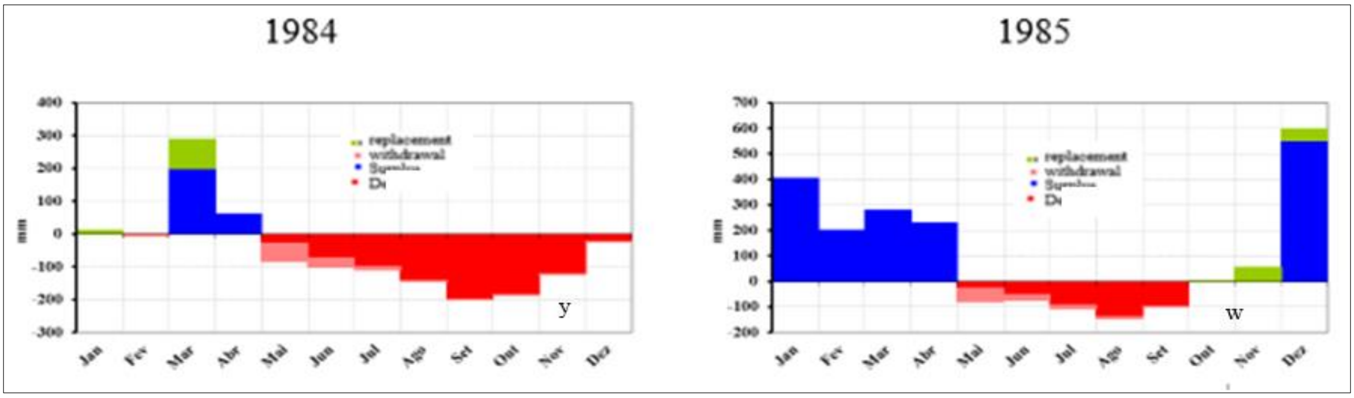
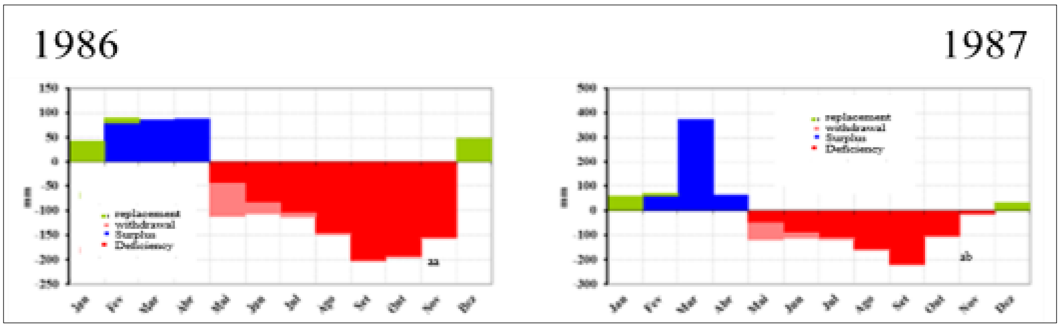


Figure 27 Representatives of the annual water balance of 1984(y) and 1985(w) for the municipal area of Santa Filomena-PI

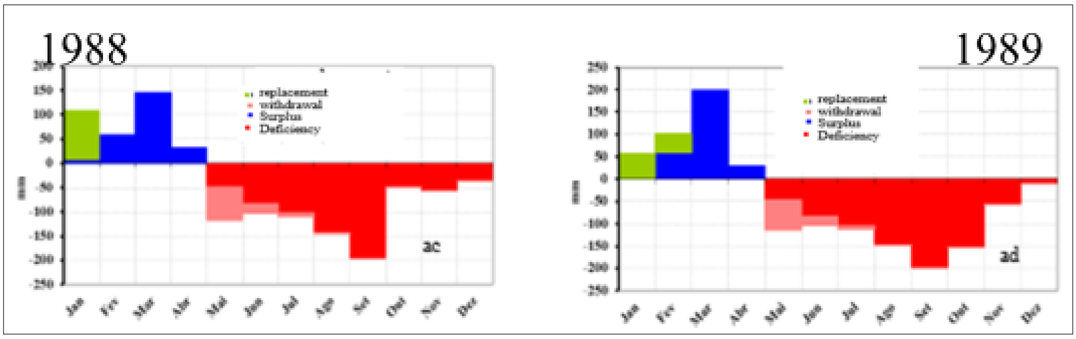
Classified as a very rainy year (1985), surpluses were recorded in the months of December to April. Low rainfall quotas in water shortages between the months of May and September, replacement and withdrawal of water was recorded in the months of another to December and between May and August. (Figure 27w).

In figures (27aa) and (27ab) referring to the years 1986 and 1987, respectively, there is water surplus between the months of February and April, deficiencies flowed between the months of May and November, with greater intensification in the year 1986.



Source: Medeiros (2022).

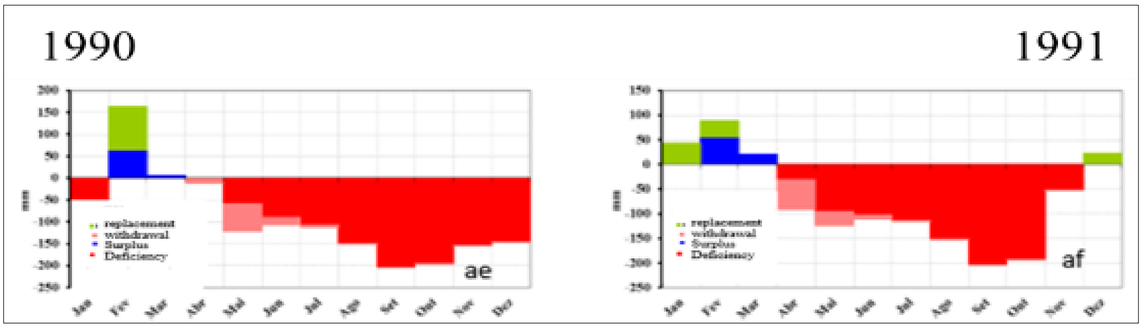
Figure 27 Representatives of the annual water balance of 1986(aa) and 1987(ab) for the municipal area of Santa Filomena-PI



Source: Medeiros (2022).

Figure 27 Representatives of the annual water balance of 1988(ac) and 1989(ad) for the municipal area of Santa Filomena-PI

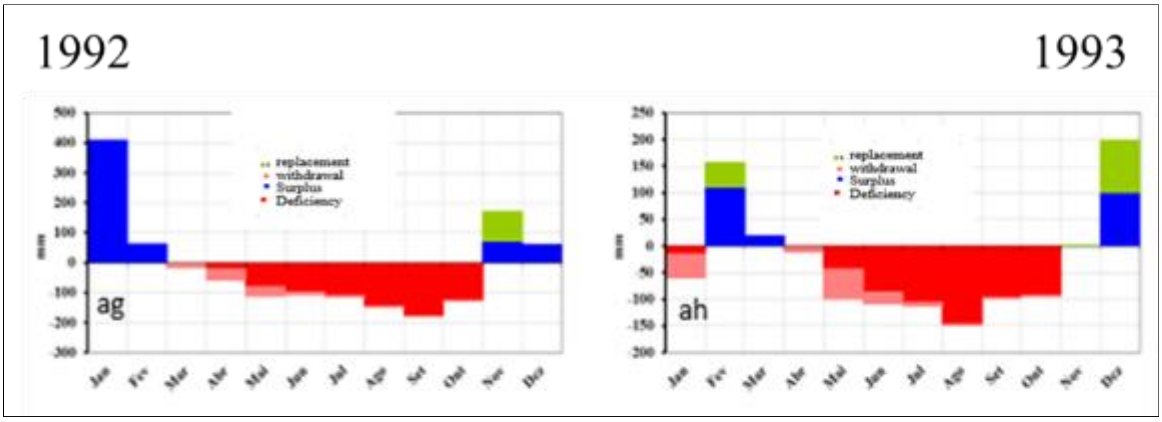
In figure (27ac) corresponding to the year 1988 and figure (27ad) to the year 1989, both years were classified as dry, there was water replenishment in the months of January, January and February, surpluses between the months of February to April with greater intensity in 1989. Water deficiencies were more intense in 1988 and predominated between the months of May and December, pre-season rains and characterization of the rainy season were not recorded due to atmospheric and the regional effects.



Source: Medeiros (2022).

Figure 27 p Representatives of the annual water balance of 1990(ae) and 1991(af) for the municipal area of Santa Filomena-PI

Figure (27ae) year 1990 and figure (27ef) year 1991 were classified as dry year, surpluses were recorded in the months of February and March, withdrawal of water in the months of April to July and their water deficiencies were recorded from May to December (1990) and from April to November (1991). The water surpluses were between the months of February and March.



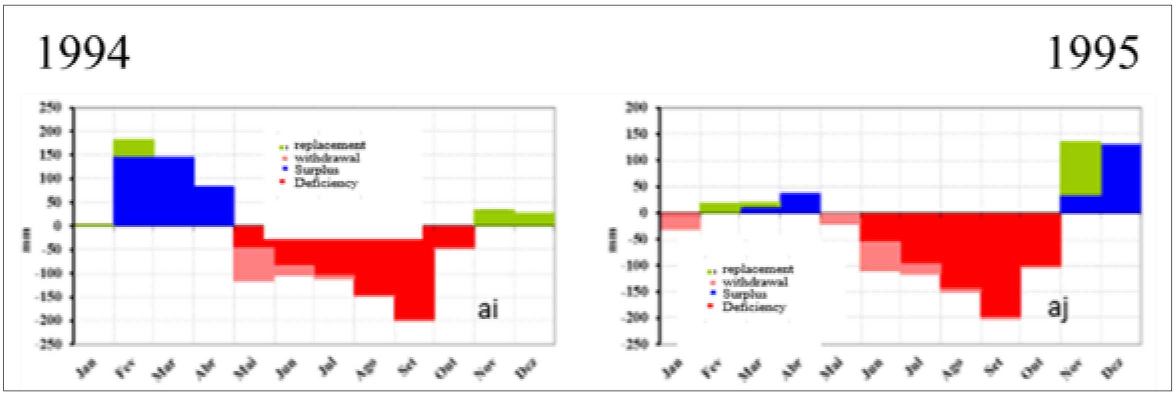
Source: Medeiros (2022).

Figure 27 q Representatives of the annual water balance of 1992(ag) and 1993(ah) for the municipal area of Santa Filomena-PI

Figure (27ag) shows water deficits between March and October, water surpluses in the months of November to February, replacement and removal of water from the soil occurred in November and from March to June, respectively. Due to the high rainfall buoyancy in January, the year 1992 was classified as rainy.

Classified as a dry year (1993) with three months of water surpluses occurring in December, February and March, water replenishment took place in December and February, water withdrawals between April and July and the predominance of water shortages were April to October and January.

As Figure (27ai) representative of the BH of the year 1994 classified as a year between normal rainfall. Water deficiencies occurred between April and October, there were water surpluses in the months of February to April, the withdrawal and replacement of water took place between May and June and between November and February, respectively.

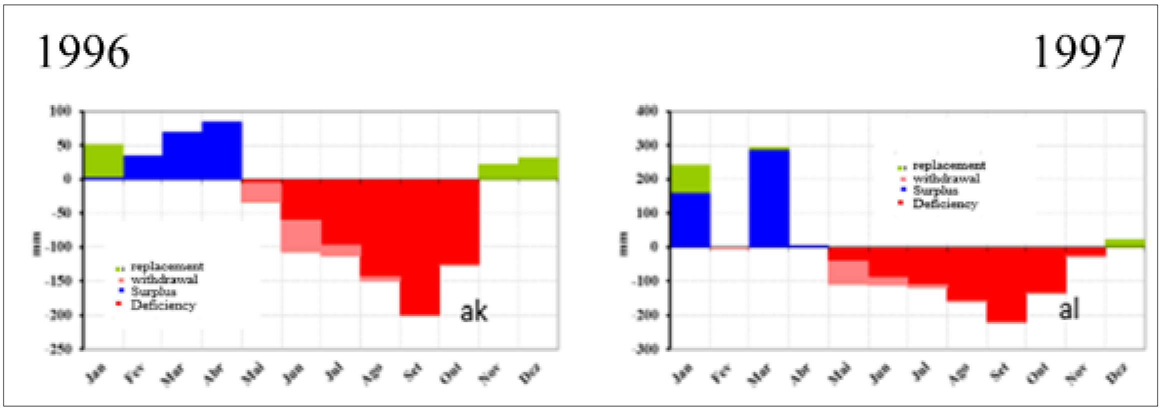


Source: Medeiros (2022).

Figure 27 r Representatives of the annual water balance of 1994(ai) and 1995(aj) for the municipal area of Santa Filomena-PI

The year 1995, classified is normal, recorded water surplus in the months of November, December, March and April, water deficiencies between the months of June to October, withdrawal of water in the months of May to August. The month of January received a small volume of water replacement. (Figure 27aj).

Water deficiencies occurred between the months of May and October; replacement of water in the months of November to January, withdrawal of water between May and August and the low surplus of normality was recorded in the months of January to April. (Figure 27ak). The year 1996 classified is normal.

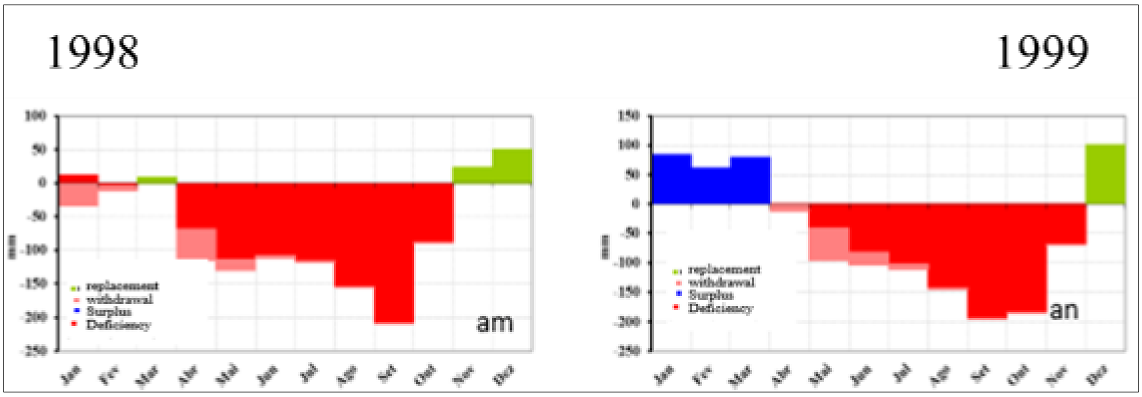


Source: Medeiros (2022).

Figure 27 s Representatives of the annual water balance of 1996(ak) and 1997(al) for the municipal area of Santa Filomena-PI

In figure (27al) there is the graph of BH corresponding to the year 1997, considered as a year with normal rainfall, surpluses were recorded in only three months (January, March and April) the replacement of water in the soil occurred in the months of December and January, the withdrawal of water from the soil was between the months of February, May and June and the water deficiencies acted between the months of May and November. The factors that provoked rains suffered blocks and the summer season acted with strong intensity.

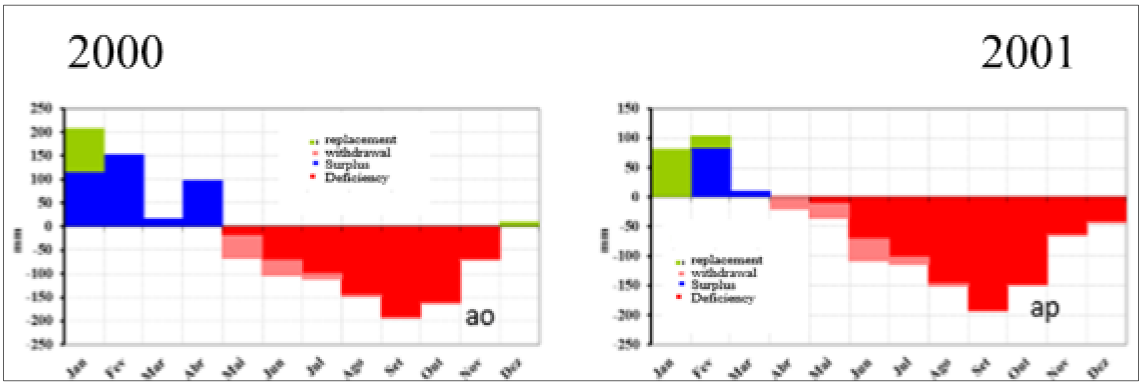
In figure (27am) there is the graph of the BH of the year 1998 which does not show water surplus, there was water replacement in the months of November, December and March but its rainfall incidences were not able to generate surpluses. Water deficiencies occurred between the months of April to October and January and February. Water withdrawals occurred in the months of January, February, April and June. The year was classified as very dry.



Source: Medeiros (2022).

Figure 27 t Representatives of the annual water balance of 1998(am) and 1999(an) for the municipal area of Santa Filomena-PI

With water surplus in the months of January to March, the deficiencies between the months of April to November and the withdrawals of water in the months of April to July and replacement of water in the month of December, the year of 1999 was classified as rain between the normal.



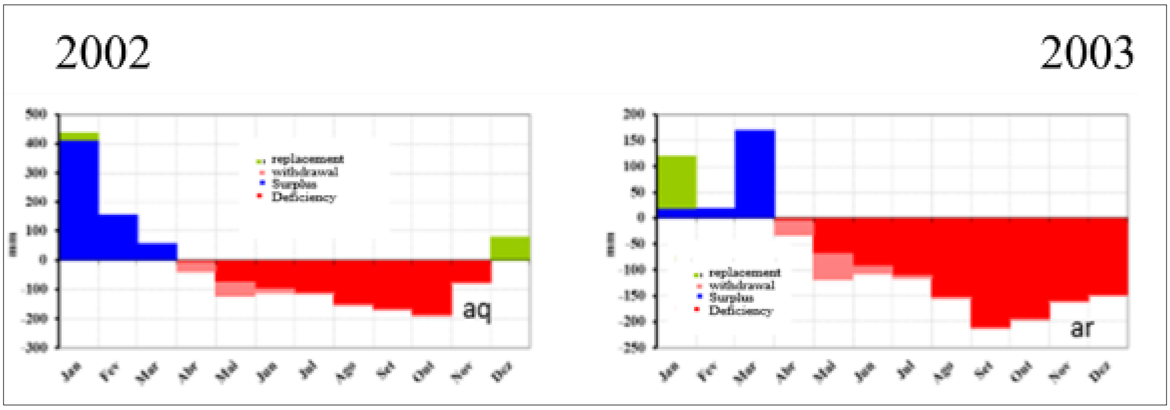
Source: Medeiros (2022).

Figure 27 u Representatives of the annual water balance of 2000(ao) and 2001(ap) for the municipal area of Santa Filomena-PI

The year 2000 (Figure 27ao) had its deficiencies extended between the months of May to November, replacement of low level water in the month of December and January, withdrawal of the waters occurred in the month of May to August and the surplus with irregularities between the January to April is considered a rainy year.

Figure (27ap) corresponds to the graph of the water balance of the year 2001, which shows water surplus in the month of February and March, water deficiency between the months of April and December, there was no replacement of water in the soil and the withdrawal took place between the months from April to August. Considered a dry year.

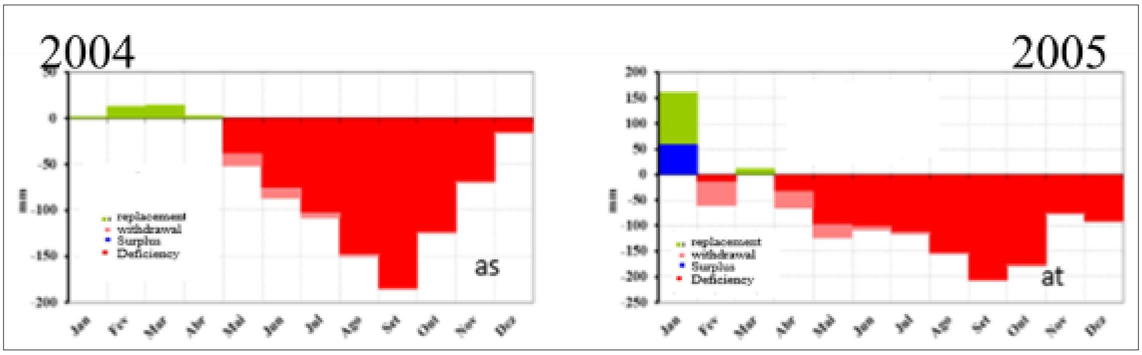
In the year 2002, Figure (27aq), classified as a year between the normality presented surplus between the months of January to March. Replacement of water occurred between the months of April to June replacement of water in the months of December and January and deficiencies between the months of April to November.



Source: Medeiros (2022).

Figure 27 v Representatives of the annual water balance of 2002(aq) and 2003(ar) for the municipal area of Santa Filomena-PI

Figure (27ar) relating to the BH graph of the year 2003 shows that water deficits predominated between April and December, water was replenished in January and water was removed from the soil between April and August, the year 2003 considered as rains between normality.



Source: Medeiros (2022).

Figure 27 w Representatives of the annual water balance of 2004(as) and 2005(at) for the municipal area of Santa Filomena-PI

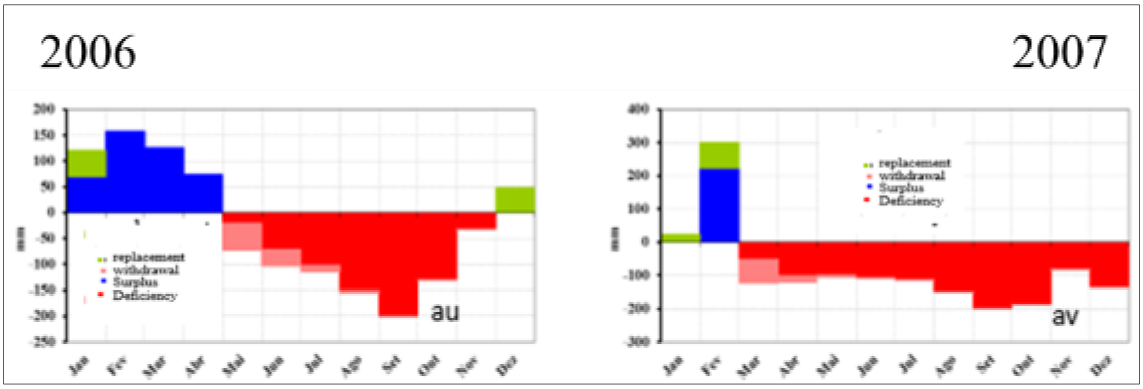
The year 2004, classified as extremely dry, where the atmospheric blockages and the providers of rain did not receive the due contributions of large scale and local scale, leaving the water deficiency of strong intensity prevailing over the months of May to December. There was no water surplus or replacement of water in the soil. The already dry soil was removed from the water between the months of May and June, leaving it cracked. (Figure 27as).

Figure (27at) shows the graphic demonstration of the BH for the year 2005, classified as dry where water shortages flowed with strong intensity in the months from April to December and February. The water replacements were from January to March which did not supply the water conditions, the water withdrawal was between the months of February, April to June.

The year 2006, considered as a rainy year where the surpluses were registered in the months of January to April, the replacement of the waters took place in the months of December and January, the withdrawal of the waters occurred between the months of May to July and the water shortages were recorded from May to November. (Figure 27au).

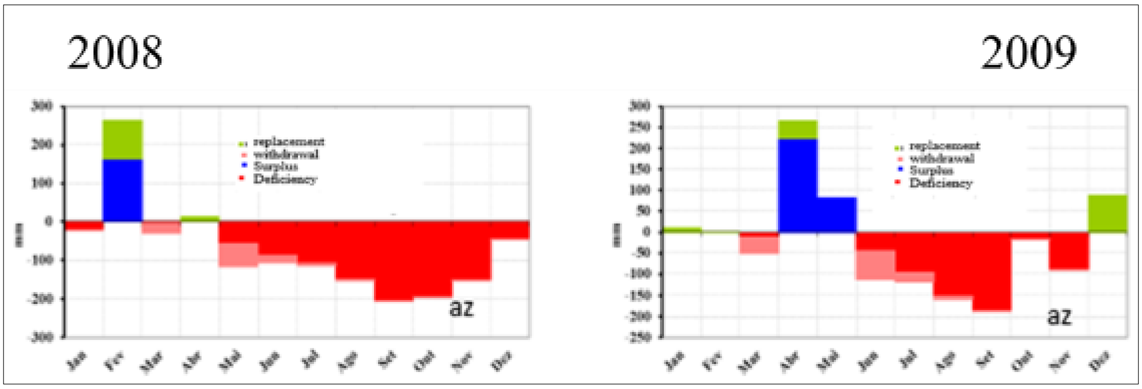
The year 2007 (Figure 27av) classified as a dry year where there was only water surplus in the month of February, the water differences were registered between the months of March to December, there was a withdrawal of water in the months of March and April, the replacement of water were between January and February.

The year 2008 classified as a dry year presented a surplus in only the month of February of low magnitude, the water replacements were in the months of February and April, the water deficiencies predominated between the months of May and January and the withdrawals of water were registered in the months of May to August. (Figure 27ax).



Source: Medeiros (2022).

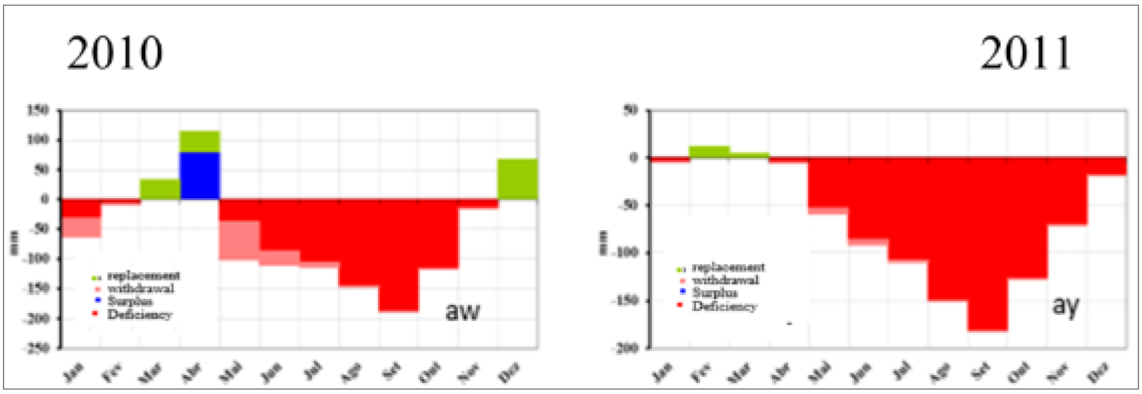
Figure 27 x Representatives of the annual water balance of 2006(au) and 2007(av) for the municipal area of Santa Filomena-PI



Source: Medeiros (2022).

Figure 27 y Representatives of the annual water balance of 2008(ax) and 2009(az) for the municipal area of Santa Filomena-PI

Figure (27az) corresponds to the year 2009, as for the rainy season, it was classified as a dry year, where water surpluses were recorded in the months of April and May, water deficiencies in the months of June to November and withdrawal of water in the months of March, June to August, water replacement took place between December and February and April. This variability came from the atmospheric blockages that reduced the factors causing rain in the study area.



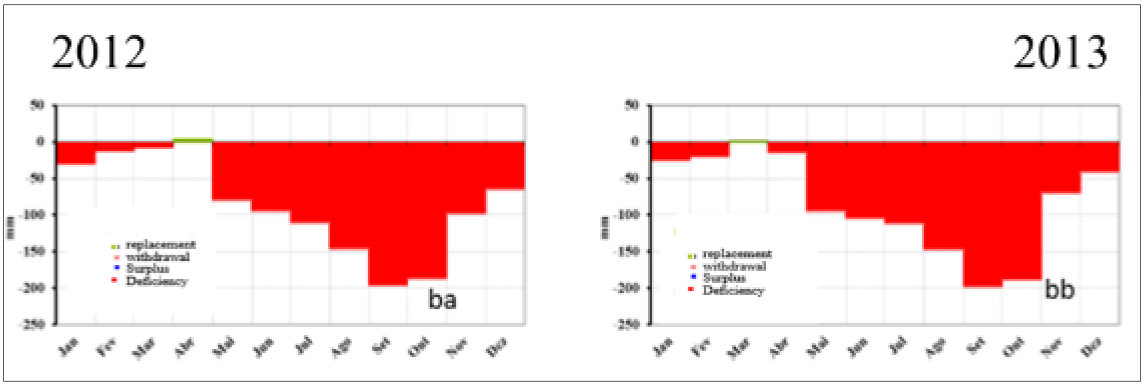
Source: Medeiros (2022).

Figure 27 z Representatives of the annual water balance of 2010(ay) and 2011(aw) for the municipal area of Santa Filomena-PI

Figure (27ay) shows the BH graph for the year 2010, classified as a dry year where surpluses occurred only in April. Replacement of water occurred in the months of March, April and December, the withdrawal of water from the soil was in the months of January, February, and from May to July. Water deficiencies predominated between the months of May to November and January and February.

Year 2011, considered dry with predominance of water shortages in 10 months (April to February), there was water replacement in February and March and water withdrawal between April and June. Rainfall rates were irregular due to the predominance of dry spells. (Figure 27aw).

In figure 27(ba) year 2012, there was a small replacement of water in the soil and the predominance of water deficiencies were total, the factors causing rain suffered floods and there was no way to meet the needs of the field. It was a year of punishment for strong summers.

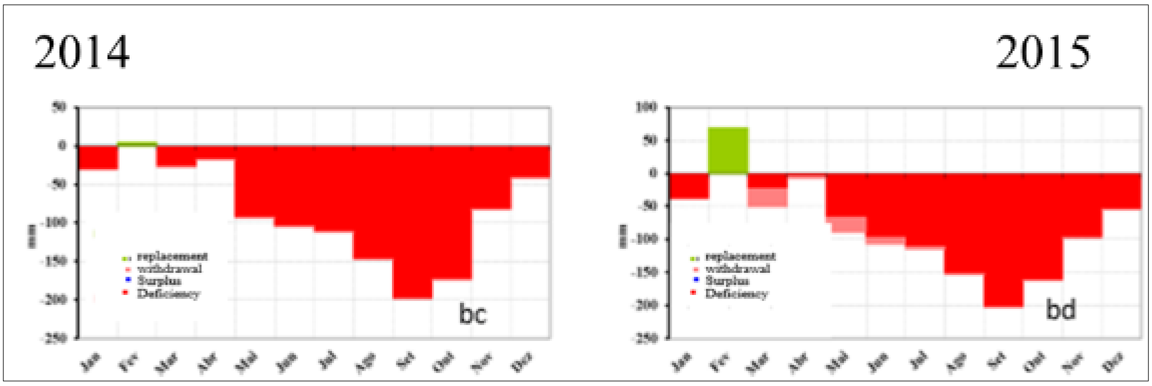


Source: Medeiros (2022).

Figure 27 aa Representatives of the annual water balance of 2012(ba) and 2013(bb) for the municipal area of Santa Filomena-PI

In 2013 (Figure 27bb) water deficit predominated in eleven (11) months from May to February, in March there was a very small amount of water in the replacement of the soil. The rain inhibiting factors acted with a strong intensity that did not supply the field capacity.

Figure (27bc) corresponding to the year 2014 showed water deficit in the months from February to January with an intense peak in the month of September. There were no water surpluses or withdrawals of water in the soil, the month of February was registered low replacement of water in the soil. The rains that occurred were not necessary to supply the 100 mm CAD.

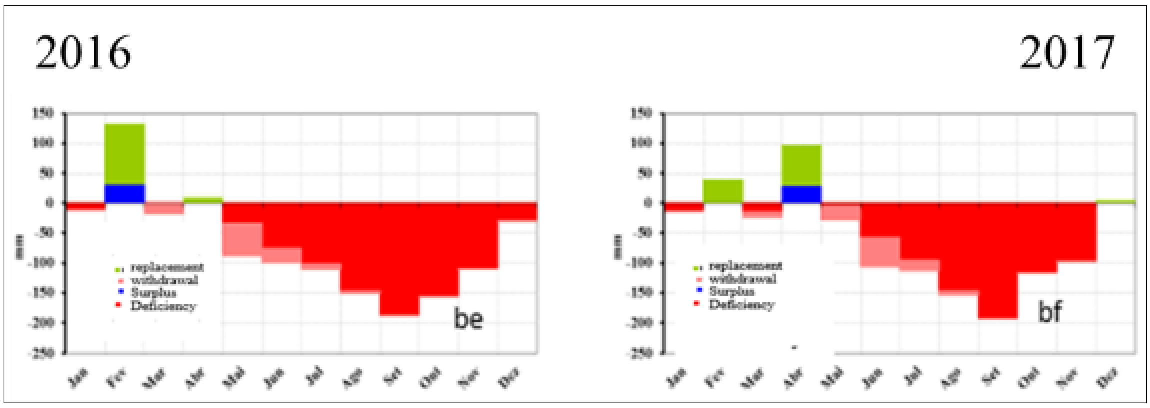


Source: Medeiros (2022).

Figure 27 ab Representatives of the annual water balance of 2014(bc) and 2015(bd) for the municipal area of Santa Filomena-PI

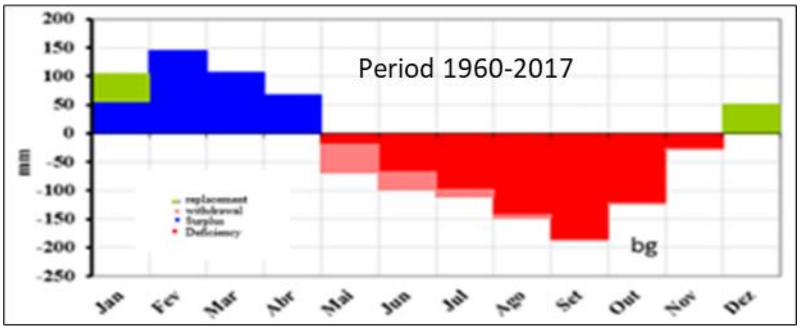
The year 2015 shown in figure (27bd) recorded water withdrawal between March and July, water replacement only in February, there was no water surplus and deficiencies predominated from March to January. The rains recorded could not exceed 100 mm and even if they had exceeded 100 the soil was extremely dry.

Figure 27(be) recorded low-intensity water surplus in February as well as water replenishment in that month and April. The withdrawal of water from the soil occurred between March and July, water deficiencies predominated from May to January, with greater intensity in August, September and October. These blockages in water surpluses may have been affected by the intensity of the strong El Niño phenomenon that acted in 2016.



Source: Medeiros (2022).

Figure 27 ac Representatives of the annual water balance of 2016(be) and 2017(bf) for the municipal area of Santa Filomena-PI



Source: Medeiros (2022).

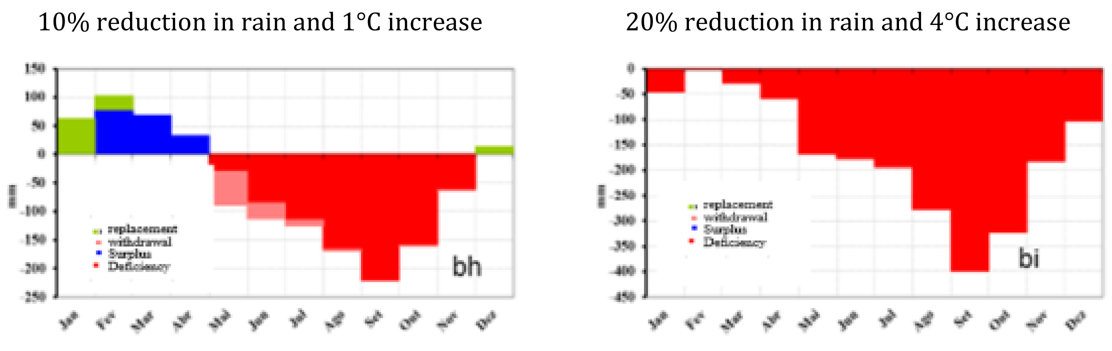
Figure 27 ad Water balance representations for the period 1960-2017 for the municipal area of Santa Filomena-PI

In figure (27bf) corresponding to the year 2017, water deficit was registered with intensity in the months of May to November, January and March, with a maximum peak in the months of August and September. The month of April was the only one with a surplus. The removal of water from the soil occurred between the months of May and August. This irregularity was caused by climatic variability and the absence of predominant rainfall factors in the region.

Figure (27bg) shows the behavior of the climatological water balance for the period 1960-2017 for the municipal area of Santa Filomena-PI. The pre-season rains (months of October and November) present with water deficiencies and the beginning rains of the characterization of the rainy season. The month of December has water replacement in the soil. Water surpluses were between January and April, water deficits between May and November and the removal of water from the soil occurred between May and August.

For future scenarios, BH was estimated with a temperature increase of 1 and 4 °C and a reduction in rainfall of -10% and 20%.

With a 10% reduction in rainfall and an average temperature increase of 1 °C, rainfall rates will be reduced and water surpluses will occur in only three (January to April). Replacements and withdrawals of water will be reduced, as the field capacity (CAD 100 mm) will not meet the water demand as well as the water deficiencies will be increased. (Figure 27bh).



Source: Medeiros (2022).

Figure 27 ae Water balance representations with a 10% reduction in rainfall and a 1°C increase in the average temperature figure (bh) and a 20% reduction in rainfall and a 4°C increase in the average temperature figure (bi) for the area municipality of Santa Filomena-PI

With a 20% reduction in rainfall and an average temperature increase of 4 °C, there will be no replacement and withdrawal of water from the ground, as well as water surpluses. There will be severe water shortages during the year. (Figure 27bi).

If these future scenarios happen, planning is necessary for the agricultural sectors, storage of drinking water and energy generation.

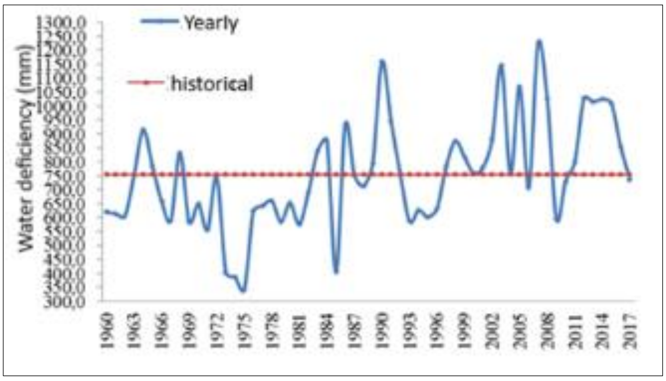
3.14. Water deficiency

Figure 28 shows the annual fluctuations of water deficits for the municipal area of Santa Filomena-PI in the period 1960-2017.

The period 1960 to 1985, the year 1989, 1993 to 1996, 2007, 2010 and 2011 stand out with deficiencies below the historical average, except for the years 1964, 1968, 1983 and 1984 whose years flowed above average. In the period from 2003 to 2009 and from 2012 to 2016, water deficits flowed above normal. Water deficiencies were greater than 700 mm in most years from 1985 to 2017, figure 28.

Such fluctuations in water deficits can be explained by the actions of the predominant meteorological systems, their local and regional effects and the intensity of summer periods causing irregularities in the rainy season, contributing to the occurrence of drought, floods, flooding, floods, collapse of barriers and rain, intense at short time intervals.

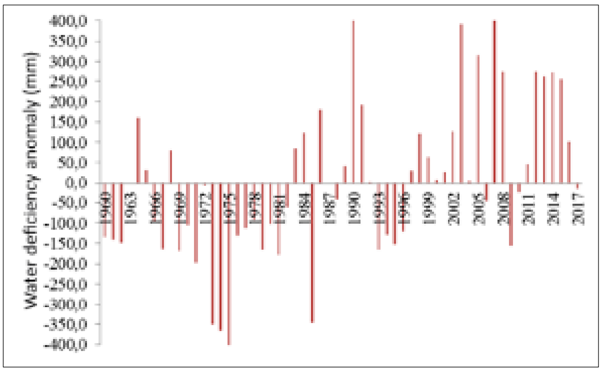
These facts are expected and contribute to the variability of aridity indexes and susceptibility to desertification, because with torrential rains tons of soil are displaced to rivers, lakes and dams, contributing to erosivity.



Source: Medeiros (2022).

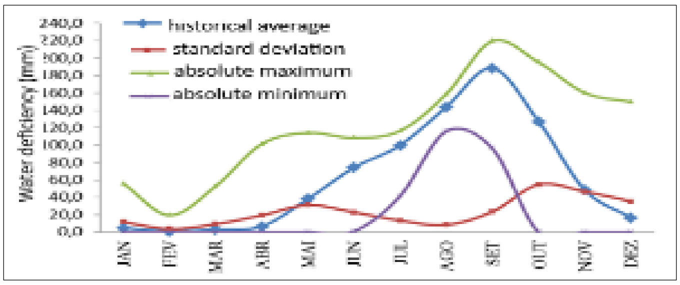
Figure 28 Representativeness of water deficiencies for the municipal area of Santa Filomena-PI in the period 1960-2017

Several authors have concluded that the water deficit anomaly presents itself as an important tool in the analysis of rainfall in the municipality. Figure 29 shows the variabilities of this element that present negative and positive fluctuations, demonstrating how the years were distributed with their rainfall quotas. As mentioned above, these variabilities can contribute to increases or decreases in aridity rates and susceptibility to desertification, since the municipality is an area that favors erosive susceptibility and desertification.



Source: Medeiros (2022).

Figure 29 Representativeness of water deficit anomalies for the municipal area of Santa Filomena-PI in the period 1960-2017



Source: Medeiros (2022).

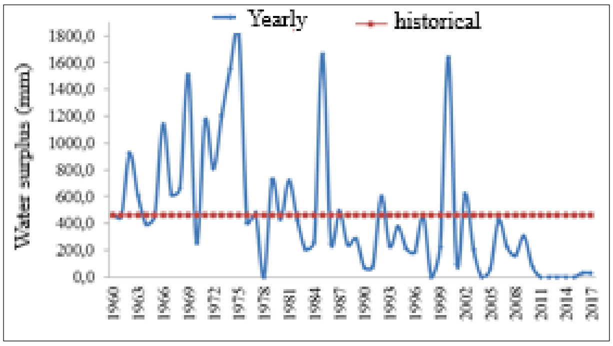
Figure 30 Distribution of monthly water deficits and their absolute maximum and minimum values and standard deviation for the municipal area of Santa Filomena-PI in the period 1960-2017

Figure 30 shows the distribution of monthly water shortages and their absolute maximum and minimum values and standard deviation for the municipal area of Santa Filomena-PI in the period 1960-2017. The average water deficit flows from 1.1 mm in February to 188.3 mm in September, with an annual total of 753.8 mm. The standard deviation ranges from 3.7 mm in February to 54.9 mm in October. With a total of 1224.6 mm.

Absolute maximum and minimum water deficits fluctuate between 19.6 mm in February to 219.6 mm in September and 1.1 mm in June to 116 mm in August respectively. These maximum and minimum oscillations are directly linked to the meteorological systems operating in the study area.

3.14.1. Water surplus

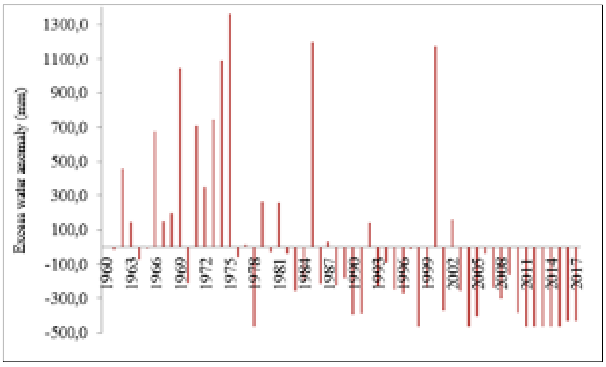
Figure 31 shows the oscillations of annual water surpluses for the municipal area of Santa Filomena-PI in the period 1960-2017 with irregularities ranging from 0 mm in the years 1978, 1988, 2004 and in the period from 2011 to 2017, with 1800 mm highlights the year 1975 and 1600 mm for the years 1985 and 2001 respectively, the other years the water surplus oscillated between 150 to 1580 mm, these irregularities may be linked to large and meso-scale phenomena that acted in the interannual rainy periods.



Source: Medeiros (2022).

Figure 31 Representativeness of annual water surpluses for the municipal area of Santa Filomena-PI in the period 1960-2017

The representativeness of annual water surplus anomalies for the municipal area of Santa Filomena-PI in the period 1960-2017 is shown in figure 32. In the period from 1960 to 1975 the anomalies were positive, demonstrating that they contributed to a better water surplus. Between the years 1976 to 2002 the irregularity of the rainy season was of significance with oscillations from -450 mm to 1100 mm. The period 2003 to 2017 predominated negative anomalies and these fluctuations contributed to the clashing of the soil, with intense and occasional rains recorded in this period.

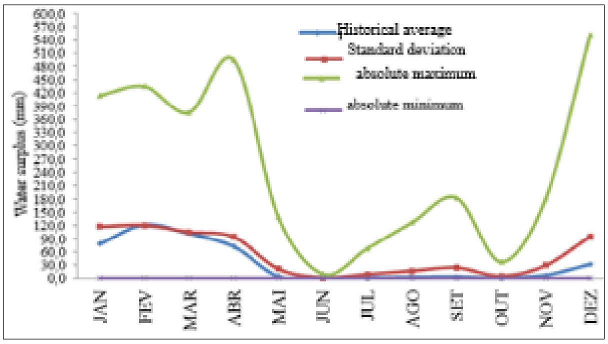


Source: Medeiros (2022).

Figure 32 Representativeness of annual water surplus anomalies for the municipal area of Santa Filomena-PI in the period 1960-2017

Figure 33 demonstrates the variability of monthly water surplus distributions and their absolute maximum and minimum values and standard deviation for the municipal area of Santa Filomena-PI in the period 1960-2017. The absolute maximum values range from 9.3 mm in the month of June to 552.4 mm in the month of December, so it is very clear that extreme rainfall has been recorded in the study area. Absolute minimum surpluses were not recorded for the study period. The average oscillates from 0.2 mm in the month of June to 122.1 mm. In the month of February, the standard deviation ranged from 1.2 mm in June to 120.7 mm in February, the excess water capacity in the study area according to information from [61].

The results obtained by the BH allowed us to verify that, due to the high atmospheric demand and the low annual values of precipitation, the occurrence of excess water and replacement of water in the soil was little observed in the studied area, these results are in accordance with the values of water surplus located in the semi-arid region.



Source: Medeiros (2022).

Figure 33 Distribution of monthly water surpluses and their absolute maximum and minimum values and standard deviation for the municipal area of Santa Filomena-PI in the period 1960-2017

3.14.2. Analysis of water balance tables for 1960-2017

Tables 21 to 81 represent the climatological water balance from the years 1960 to 2017 in the municipality of Santa Filomena, showing the oscillations: Mean air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Evaporation (ETR), Water Deficiency (DEF) and Annual Excess Water (EXC).

Table 21 Climatological water balance of the year 1960 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.8	250.3	12.5	126.5	126.5	0.0	91.5
February	25.6	280.8	12.4	113.9	113.9	0.0	166.8
March	25.3	248.5	12.2	118.4	118.4	0.0	130.1
April	25.5	193.7	11.9	115.6	115.6	0.0	78.1
May	25.3	48.2	11.7	114.7	96.7	17.9	0.0
June	24.8	6.2	11.5	101.0	37.7	63.3	0.0
July	25.1	1.0	11.5	109.1	14.1	95.0	0.0
August	27.0	0.3	11.6	143.5	5.4	138.1	0.0
September	29.5	11.4	11.8	195.1	12.8	182.3	0.0
October	28.5	71.6	12.1	182.5	71.7	110.8	0.0
November	26.8	131.4	12.3	144.1	131.4	12.7	0.0
December	26.2	207.3	12.5	139.6	139.6	0.0	0.0
Annual	26.3	1450.5	144.0	1604.2	984.1	620.2	466.5

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Souse: Medeiros (2022).

With an average annual temperature of 26.3°C. Annual rainfall with 1450.5 mm. ETP and EVR with 1604.2 mm and 984.1 mm, respectively, with evapotranspiration greater than precipitation of 9.6% and evaporation greater than rainfall in 47.4%, The year 1960 recorded an annual water deficit of 620.2 mm and water surplus of 466.5 mm. (Table 21). The value of the Photoperiod is annual and corresponds to 144 hours of sunlight, the monthly fluctuations and the differential as it depends on the cloud cover for each day.

Table 22 Climatological water balance of the year 1961 for the municipality of Santa Filomena

Months	T (°C)	P (mm)	N (hora)	ETP (mm)	ETR (mm)	DEF (mm)	EXC (mm)
January	25.9	247.7	12.5	128.3	128.3	0.0	87.3
February	25.9	277.4	12.4	118.9	118.9	0.0	158.5
March	25.2	245.7	12.2	117.2	117.2	0.0	128.6
April	25.5	192.0	11.9	116.8	116.8	0.0	75.3
May	25.4	48.6	11.7	116.0	97.6	18.3	0.0
June	25.0	6.5	11.5	104.3	38.3	66.0	0.0
July	25.0	1.1	11.5	107.0	13.6	93.5	0.0
August	26.9	0.3	11.6	142.5	5.4	137.2	0.0
September	29.2	11.8	11.8	189.1	13.1	176.0	0.0
October	28.4	71.6	12.1	180.7	71.8	108.9	0.0
November	26.8	130.4	12.3	144.7	130.4	14.3	0.0
December	26.1	205.5	12.5	137.6	137.6	0.0	0.0
Annual	26.3	1438.6	144.0	1603.2	989.0	614.2	449.6

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

Table 23 Climatological water balance of the year 1962 for the municipality of Santa Filomena

Months	T (°C)	P (mm)	N (hora)	ETP (mm)	ETR (mm)	DEF (mm)	EXC (mm)
January	25.8	296.7	12.5	127.1	127.1	0.0	169.6
February	25.7	385.6	12.4	115.4	115.4	0.0	270.1
March	25.1	292.0	12.2	115.8	115.8	0.0	176.2
April	25.4	265.9	11.9	114.5	114.5	0.0	151.4
May	25.3	78.9	11.7	114.8	109.0	5.7	0.0
June	25.0	14.2	11.6	104.4	55.7	48.8	0.0
July	25.2	2.3	11.5	110.5	21.0	89.5	0.0
August	27.2	0.7	11.6	147.3	8.1	139.2	0.0
September	29.4	9.4	11.8	195.1	11.3	183.8	0.0
October	28.6	89.2	12.1	185.1	89.5	95.7	0.0
November	27.0	104.2	12.3	147.3	104.2	43.0	0.0
December	26.1	393.6	12.4	136.8	136.8	0.0	156.9
Annual	26.3	1932.8	144.0	1614.3	1008.6	605.7	924.2

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

Table 22 shows the fluctuations of the year 1961, presented an annual water deficit of 614.2 mm, with a water surplus of 449.6 mm, The average annual temperature of 26.3 °C and with a total rainfall of 1174.7 the annual ETP and EVR were 1603.2 mm and 989 mm, respectively. It evapotranspired 89.7% of the precipitation value and evaporated 45.5% above the annual rainfall value.

Table 24 Climatological water balance of the year 1963 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.8	139.7	12.5	126.2	126.2	0.0	13.5
February	25.7	331.1	12.4	115.7	115.7	0.0	215.4
March	25.3	265.3	12.2	117.3	117.3	0.0	148.0
April	25.6	249.8	11.9	116.7	116.7	0.0	133.1
May	25.5	36.4	11.7	116.7	91.6	25.1	0.0
June	25.1	0.0	11.5	105.5	29.2	76.3	0.0
July	25.6	0.0	11.5	115.7	10.7	105.0	0.0
August	27.5	0.0	11.6	153.2	3.8	149.3	0.0
September	29.7	0.0	11.8	202.8	0.9	201.9	0.0
October	28.9	0.7	12.1	194.1	0.8	193.3	0.0
November	27.3	226.5	12.3	154.8	154.8	0.0	0.0
December	26.5	271.4	12.5	144.9	144.9	0.0	98.2
Annual	26.6	1520.9	144.0	1663.9	912.9	751.0	608.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

Table 25 Climatological water balance of the year 1964 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.2	382.5	12.5	134.8	134.8	0.0	164.1
February	25.9	348.6	12.4	119.8	119.8	0.0	228.8
March	25.2	31.3	12.2	118.3	89.4	28.9	0.0
April	25.4	10.4	11.9	115.7	37.7	78.0	0.0
May	25.1	0.0	11.7	111.7	9.8	101.8	0.0
June	24.6	0.0	11.5	99.6	3.0	96.6	0.0
July	24.9	0.0	11.5	107.0	1.2	105.9	0.0
August	26.7	0.0	11.6	138.0	0.5	137.6	0.0
September	28.9	0.0	11.8	182.3	0.1	182.2	0.0
October	28.2	34.4	12.1	175.6	34.4	141.2	0.0
November	26.4	94.0	12.3	136.9	94.0	42.9	0.0
December	25.6	144.3	12.5	127.9	127.9	0.0	0.0
Annual	26.1	1045.5	144.0	1567.7	652.7	915.1	392.8

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022)

With annual precipitation of 1174.7 mm, average temperature of 26.3 °C, evapotranspiration and evaporation of 1614.3 mm and 1008.6 mm, respectively. It evapotranspired 19.7% above the rainfall index and evaporated 91.6% less than the pluviometric value. The annual water deficit recorded was 605.7 mm, with a water surplus of 924.7 mm year-1. (Table 23). Year 1962. In 1963 it rained 1174.7 mm. It evapotranspired 1663.9 mm year-1 and evaporated 912.9 mm year-1, corresponding to 70.7 evapotranspiration of the precipitation value and 28.7% evaporated below the precipitation value. (Table 24).

Table 26 Climatological water balance of the year 1965 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.4	123.9	12.5	120.0	120.0	0.0	0.0
February	25.5	431.0	12.4	112.7	112.7	0.0	222.2
March	25.0	268.0	12.2	113.9	113.9	0.0	154.1
April	25.4	195.8	11.9	114.1	114.1	0.0	81.7
May	25.4	21.4	11.7	116.2	82.6	33.5	0.0
June	25.0	0.0	11.5	104.0	25.1	78.9	0.0
July	25.2	0.0	11.5	110.9	9.2	101.7	0.0
August	27.2	0.0	11.6	147.6	3.5	144.1	0.0
September	29.6	0.0	11.8	199.0	0.9	198.1	0.0
October	28.9	40.2	12.1	191.4	40.3	151.1	0.0
November	27.2	85.6	12.3	152.7	85.6	67.1	0.0
December	26.5	134.3	12.5	144.9	134.3	10.6	0.0
Annual	26.4	1300.2	144.0	1627.3	842.2	785.1	458.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC). Source: Medeiros (2022)

Table 27 Climatological water balance of the year 1966 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.2	244.0	12.5	133.7	133.7	0.0	19.8
February	26.0	551.7	12.4	121.1	121.1	0.0	430.6
March	25.4	317.5	12.2	121.1	121.1	0.0	196.4
April	25.6	611.9	11.9	117.7	117.7	0.0	494.2
May	25.4	25.0	11.7	115.3	84.5	30.8	0.0
June	25.1	0.0	11.5	104.7	26.3	78.4	0.0
July	25.3	0.0	11.5	111.5	9.6	101.9	0.0
August	27.1	0.0	11.6	145.1	3.6	141.5	0.0
September	29.4	0.0	11.8	195.0	0.9	194.1	0.0
October	28.6	89.2	12.1	185.0	89.3	95.7	0.0
November	26.9	129.6	12.3	145.9	129.6	16.3	0.0
December	26.2	146.8	12.5	137.4	137.4	0.0	0.0
Annual	26.4	2115.7	144.0	1633.4	974.7	658.7	1141.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC). Source: Medeiros (2022)

Table 25 shows the water balance oscillations corresponding to the year 1964 with evapotranspired power of 66.7% mm of the precipitation value and 60.2% of the annual precipitation value evaporated. With 915.2 mm of annual deficiency and 392.8 mm of water surplus.

Table 26 shows the fluctuations resulting from the year 1965 in the municipality of Santa Filomena - PI. With an average annual rainfall of 1300.4 mm. Evapotranspiration and annual evaporation of 1627.3 mm and 842.2 mm respectively. Evapotranspired 79.9% of annual precipitation. It evaporated 46.6% of the annual precipitation value, 1965 presented a water deficit of 785.1 mm and an annual surplus of 458 mm.

Table 27 with 658.7 mm of water deficiency and 1141 mm of water surplus the year 1966 recorded 2115.7 mm evapotranspiration 71% of the annual precipitation and evaporated 217.1% of the annual rates.

Table 28, referring to the year 1967, with a total annual rainfall of 1605.3 mm, annual ETP and EVR of 1579.3 mm and 988.8 mm, respectively. It evaporated 62.4%, evapotranspired 101.7% of the annual precipitation value. The water deficit recorded was 590.4 mm and the water surplus was 616.5 mm.

Table 28 Climatological water balance of the year 1968 for the municipality of Santa Filomena

Months	**T**	**P**	**N**	**ETP**	**ETR**	**DEF**	**EXC**
	(°C)	**(mm)**	**(hora)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**
January	25.7	198.0	12.5	125.8	125.8	0.0	72.2
February	25.6	386.7	12.4	115.1	115.1	0.0	271.6
March	25.1	212.3	12.2	115.8	115.8	0.0	96.5
April	25.4	236.4	11.9	114.8	114.8	0.0	121.6
May	25.4	38.9	11.7	116.0	92.7	23.4	0.0
June	24.9	0.0	11.5	103.2	29.8	73.5	0.0
July	24.9	0.0	11.5	106.9	10.8	96.0	0.0
August	26.8	0.0	11.6	140.6	4.3	136.3	0.0
September	29.1	35.2	11.8	187.1	36.3	150.8	0.0
October	28.3	67.8	12.1	178.4	68.0	110.4	0.0
November	26.6	165.4	12.3	141.0	141.0	0.0	0.0
December	26.0	264.6	12.5	134.5	134.5	0.0	54.6
Annual	26.2	1605.3	144.0	1579.3	988.8	590.4	616.5

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC).

Source: Medeiros (2022)

Evapotranspired 89.52% of the annual precipitation and with 84% of the evaporation. The annual rainfall of 1451.7 mm, water deficit of 823.2 mm water surplus of 662.4 mm were the fluctuations of the year 1968 according to Table 29.

Table 29 Climatological water balance of the year 1969 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.5	267.1	12.5	122.4	122.4	0.0	62.1
February	25.5	336.8	12.4	112.3	112.3	0.0	224.5
March	24.9	300.0	12.2	112.9	112.9	0.0	187.1
April	25.3	301.5	11.9	112.9	112.9	0.0	188.6
May	25.2	19.7	11.7	112.1	80.0	32.1	0.0
June	25.0	0.0	11.5	104.1	25.7	78.4	0.0
July	25.3	0.0	11.5	111.8	9.4	102.3	0.0
August	27.2	0.0	11.6	148.4	3.5	144.9	0.0
September	29.6	0.0	11.8	198.1	0.9	197.2	0.0
October	28.8	0.0	12.1	190.6	0.1	190.5	0.0
November	27.2	64.8	12.3	151.7	64.8	86.9	0.0
December	26.5	161.8	12.5	144.4	144.4	0.0	0.0
Annual	26.3	1451.7	144.0	1621.6	789.3	832.3	662.4

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC). Source: Medeiros (2022)

The year 1969 registered a water deficit of 585.8 mm, a water surplus of 1511.3 mm and annual precipitation of 2617.2 mm, evapotranspiration of 154.71% and evaporation of 136.66% of the annual value of precipitation (Table 30).

Table 30 Climatological water balance of the year 1969 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.3	332.7	12.5	136.2	136.2	0.0	196.5
February	26.3	526.2	12.4	124.2	124.2	0.0	402.0
March	25.7	500.1	12.2	124.7	124.7	0.0	375.4
April	26.0	266.6	11.9	122.6	122.6	0.0	144.0
May	25.9	77.9	11.7	123.7	114.6	9.0	0.0
June	25.3	0.0	11.5	106.7	41.5	65.2	0.0
July	25.3	0.0	11.5	111.0	14.6	96.4	0.0
August	27.3	0.0	11.6	149.1	5.6	143.5	0.0
September	29.7	0.0	11.8	202.0	1.4	200.6	0.0
October	28.9	123.1	12.1	194.3	123.2	71.1	0.0
November	27.2	210.1	12.3	152.1	152.1	0.0	0.0
December	26.6	580.5	12.5	145.2	145.2	0.0	393.4
Annual	26.7	2617.2	144.0	1691.7	1105.9	585.8	1511.3

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC). Source: Medeiros (2022).

Table 31 shows the BH statement for the year 1970 with 127% evaporated and 75.49% evapotranspiration of the annual precipitation which recorded 1206.5 mm, annual water deficit of 648.3 mm and water surplus of 256.7 mm.

Table 31 Climatological water balance of the year 1970 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.3	463.5	12.5	136.3	136.3	0.0	227.2
February	26.1	142.3	12.4	121.8	121.8	0.0	20.5
March	25.4	89.7	12.2	121.2	116.7	4.5	0.0
April	25.7	155.2	11.9	119.2	119.2	0.0	9.0
May	25.4	115.6	11.7	116.7	116.7	0.0	0.0
June	24.8	59.0	11.5	101.5	93.3	8.3	0.0
July	24.9	30.3	11.5	106.5	64.8	41.7	0.0
August	26.8	0.0	11.6	139.9	22.7	117.2	0.0
September	29.2	0.0	11.8	188.1	6.3	181.8	0.0
October	28.3	0.0	12.1	178.1	0.9	177.2	0.0
November	26.6	38.3	12.3	140.1	38.4	101.6	0.0
December	25.7	112.6	12.5	128.7	112.6	16.1	0.0
Annual	26.3	1206.5	144.0	1598.1	949.8	648.3	256.7

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC). Source: Medeiros (2022).

The evapotranspiration and evaporation values were below the rainfall indices, the deficiency and the water surpluses registered 556.2 mm and 1172.5 mm, respectively, as shown in Table 32.

Table 32 Climatological water balance of the year 1972 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.4	483.5	12.5	121.6	121.6	0.0	351.4
February	25.3	467.9	12.4	109.8	109.8	0.0	358.1
March	24.8	343.9	12.2	111.9	111.9	0.0	232.0
April	25.3	344.1	11.9	113.1	113.1	0.0	231.0
May	25.2	101.5	11.7	112.9	112.3	0.6	0.0
June	24.7	0.0	11.5	101.3	56.8	44.5	0.0
July	24.9	0.0	11.5	107.5	21.3	86.2	0.0
August	26.8	0.0	11.6	140.6	8.3	132.2	0.0
September	29.1	0.0	11.8	185.9	2.3	183.6	0.0
October	28.2	84.3	12.1	176.4	84.6	91.8	0.0
November	26.5	122.3	12.3	139.5	122.3	17.2	0.0
December	25.7	220.2	12.5	130.9	130.9	0.0	0.0
Annual	26.0	2167.7	144.0	1551.4	995.2	556.2	1172.5

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

The year 1973 recorded annual rainfall of 1757.9 mm, with water deficit of 746.1 mm and water surplus of 812.7 mm, the evaporative rates were 1691.3 mm and 945.2 mm respectively. (Table 33).

Table 33 Climatological water balance of the year 1973 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.7	267.3	12.5	123.8	123.8	0.0	143.5
February	25.8	378.2	12.4	116.1	116.1	0.0	262.1
March	25.1	265.1	12.2	114.8	114.8	0.0	150.3
April	25.6	373.6	11.9	116.9	116.9	0.0	256.7
May	25.6	43.0	11.7	118.4	96.0	22.5	0.0
June	25.3	0.0	11.5	107.0	30.9	76.1	0.0
July	25.6	0.0	11.5	115.5	11.0	104.4	0.0
August	27.6	0.0	11.6	155.0	4.0	151.0	0.0
September	29.8	0.0	11.8	206.5	0.9	205.6	0.0
October	29.2	15.0	12.1	201.7	15.1	186.6	0.0
November	27.7	182.5	12.3	161.9	161.9	0.0	0.0
December	27.0	233.2	12.5	153.7	153.7	0.0	0.0
Annual	26.7	1757.9	144.0	1691.3	945.2	746.1	812.7

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

The year 1974 represented by Table 34 registered a water deficit of 402.8 mm, a water surplus of 1208.7 mm, annual rainfall of 2422.1 mm and evaporative values of 1616.2 mm and 1213.4 mm respectively.

Table 34 Climatological water balance of the year 1974 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.6	312.3	12.5	141.2	141.2	0.0	171.1
February	26.3	373.1	12.4	126.1	126.1	0.0	247.0
March	25.5	397.9	12.2	123.0	123.0	0.0	274.9
April	25.6	291.2	11.9	118.2	118.2	0.0	173.0
May	25.4	73.6	11.7	116.4	108.4	8.0	0.0
June	24.9	0.0	11.5	101.9	41.7	60.3	0.0
July	25.1	0.0	11.5	108.5	15.6	92.9	0.0
August	26.9	10.0	11.6	142.1	15.8	126.2	0.0
September	29.3	73.8	11.8	190.6	75.3	115.3	0.0
October	28.3	315.2	12.1	178.9	178.9	0.0	36.9
November	26.6	250.6	12.3	140.3	140.3	0.0	110.3
December	25.7	324.4	12.5	128.9	128.9	0.0	195.5
Annual	26.4	2422.1	144.0	1616.2	1213.4	402.8	1208.7

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

The year 1974 recorded annual rainfall of 3290 mm, evapotranspiration of 1554.9 mm and evaporation of 1167.7 mm, water deficiencies and surpluses were 387.2 mm and 2122.3 mm, as shown in Table 35.

Table 35 Climatological water balance of the year 1974 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.2	398.7	12.5	118.1	118.1	0.0	280.6
February	25.2	646.0	12.4	109.2	109.2	0.0	536.8
March	24.8	637.1	12.2	112.2	112.2	0.0	524.9
April	25.1	361.6	11.9	110.6	110.6	0.0	251.0
May	25.1	292.3	11.7	111.8	111.8	0.0	180.5
June	24.8	55.6	11.5	101.9	92.7	9.3	0.0
July	25.1	0.0	11.5	109.4	41.8	67.5	0.0
August	27.0	0.0	11.6	143.4	16.1	127.4	0.0
September	29.2	0.0	11.8	187.3	4.3	183.0	0.0
October	28.3	263.1	12.1	177.3	177.3	0.0	0.0
November	26.6	284.1	12.3	140.8	140.8	0.0	129.8
December	25.9	351.5	12.5	132.9	132.9	0.0	218.6
Annual	26.0	3290.0	144.0	1554.9	1167.7	387.2	2122.3

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022)

It rained 3017.2 mm, there was a water surplus of 1828.4 mm, deficiencies were 341.7 mm, evapotranspired 1530.5 mm, practically half of what precipitated and evaporated 1188.8 mm. (Table 36).

Table 36 Climatological water balance of the year 1975 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.5	533.6	12.5	123.8	123.8	0.0	409.8
February	25.5	548.4	12.4	113.5	113.5	0.0	434.9
March	24.9	427.2	12.2	113.7	113.7	0.0	313.5
April	25.2	356.4	11.9	112.3	112.3	0.0	244.1
May	25.0	251.0	11.7	111.2	111.2	0.0	139.8
June	24.6	83.9	11.5	99.0	97.9	1.1	0.0
July	24.9	0.0	11.5	106.8	56.4	50.4	0.0
August	26.7	0.0	11.6	138.1	22.1	116.0	0.0
September	28.9	0.0	11.8	180.4	6.2	174.2	0.0
October	28.0	175.9	12.1	170.1	170.1	0.0	0.0
November	26.3	410.8	12.3	135.8	135.8	0.0	182.0
December	25.4	230.0	12.5	125.7	125.7	0.0	104.3
Annual	25.9	3017.2	144.0	1530.5	1188.8	341.7	1828.4

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

Table 37 shows the BH fluctuations for the year 1976, with an average rainfall of 1374.5 mm, evapotranspiration above the rainfall values, 82% of the annual rainfall value evaporated, water deficiencies recorded 623.5 mm and surpluses with annual total of 410 mm.

Table 37 Climatological water balance of the year 1976 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.2	205.9	12.5	116.6	116.6	0.0	55.5
February	25.3	276.8	12.4	109.9	109.9	0.0	166.9
March	24.8	230.3	12.2	111.7	111.7	0.0	118.6
April	25.2	179.9	11.9	110.8	110.8	0.0	69.1
May	25.1	50.0	11.7	111.4	95.9	15.5	0.0
June	24.9	3.6	11.5	102.4	37.6	64.9	0.0
July	25.1	0.9	11.5	108.7	14.2	94.5	0.0
August	27.0	0.0	11.6	143.8	5.2	138.6	0.0
September	29.4	5.1	11.8	194.4	6.5	188.0	0.0
October	28.7	72.5	12.1	187.7	72.6	115.1	0.0
November	27.1	143.3	12.3	150.2	143.3	6.9	0.0
December	26.3	206.3	12.5	140.2	140.2	0.0	0.0
Annual	26.2	1374.5	144.0	1588.0	964.5	623.5	410.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

Table 38 shows the result of the BH for the year 1977, 1472.7 mm of precipitation, 1636.2 mm of evapotranspiration, 163.5 mm of transpiration more than the rainfall values, 478.3 mm of less than annual rainfall evaporation, the water surpluses and deficiencies recorded were 641.8 mm and 478.3 mm, respectively.

Table 38 Climatological water balance of the year 1977 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.0	254.6	12.5	130.1	130.1	0.0	92.3
February	25.8	286.5	12.4	116.6	116.6	0.0	169.9
March	25.2	249.8	12.2	117.0	117.0	0.0	132.8
April	25.4	197.4	11.9	114.1	114.1	0.0	83.3
May	25.5	48.9	11.7	116.3	98.0	18.4	0.0
June	25.1	6.2	11.5	105.0	38.2	66.8	0.0
July	25.2	0.9	11.5	110.2	13.5	96.7	0.0
August	27.1	0.3	11.6	145.3	5.1	140.2	0.0
September	29.6	11.4	11.8	198.2	12.6	185.6	0.0
October	28.8	72.5	12.1	189.3	72.6	116.7	0.0
November	27.2	133.7	12.3	151.2	133.7	17.5	0.0
December	26.4	210.5	12.5	142.8	142.8	0.0	0.0
Annual	26.4	1472.7	144.0	1636.2	994.4	641.8	478.3

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

The year 1978 had a rainfall of 952.9 mm, the recorded evapotranspiration rates were 1612.9 mm, evapotranspiration was one and a half times above the rainfall, and evaporation with 952.9 equaling the rainfall, there was no water surplus, the deficiencies water was 659.9 mm. (Table 39).

Table 39 Climatological water balance of the year 1978 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.1	140.5	12.5	132.3	132.3	0.0	0.0
February	25.9	137.6	12.4	118.4	118.4	0.0	0.0
March	25.3	137.0	12.2	118.9	118.9	0.0	0.0
April	25.4	123.0	11.9	114.3	114.3	0.0	0.0
May	25.3	66.5	11.7	113.7	86.9	26.8	0.0
June	24.8	18.1	11.5	101.6	37.3	64.3	0.0
July	25.1	4.8	11.5	109.1	14.3	94.8	0.0
August	27.0	1.6	11.6	143.1	5.5	137.6	0.0
September	29.3	25.3	11.8	192.2	26.4	165.8	0.0
October	28.5	74.0	12.1	182.6	74.2	108.5	0.0
November	26.9	89.9	12.3	146.6	89.9	56.7	0.0
December	26.3	134.6	12.5	140.1	134.6	5.4	0.0
Annual	26.3	952.9	144.0	1612.9	952.9	659.9	0.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

Table 40 shows the result of BH for the year 1979, with annual rainfall of 1796.8 mm, evapotranspiration and annual evaporation of 1657.9 mm and 1071.3 mm respectively, surpluses and water deficits were 586, 7mm and 725.6mm.

Table 40 Climatological water balance of the year 1979 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.0	291.7	12.5	130.7	130.7	0.0	161.0
February	25.9	374.3	12.4	118.3	118.3	0.0	256.0
March	25.4	287.3	12.2	120.2	120.2	0.0	167.1
April	25.7	258.2	11.9	118.2	118.2	0.0	140.1
May	25.6	75.7	11.7	117.8	110.1	7.8	0.0
June	25.3	13.3	11.5	107.3	53.3	54.0	0.0
July	25.3	2.2	11.5	110.9	19.2	91.8	0.0
August	27.2	0.7	11.6	146.8	7.3	139.5	0.0
September	29.7	9.7	11.8	202.2	11.4	190.9	0.0
October	28.8	87.4	12.1	190.3	87.6	102.8	0.0
November	27.2	157.8	12.3	151.5	151.5	0.0	0.0
December	26.5	238.6	12.5	143.5	143.5	0.0	1.4
Annual	26.5	1796.8	144.0	1657.9	1071.3	586.7	725.6

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

The year 1980 represented in Table 41 has an average annual rainfall of 1437.8 mm, evapotranspiration of 1654.4 evapotranspiration more than the precipitation values, annual evaporation of 1003.3 mm, with a water surplus of 434.5 mm and water deficit of 651.1mm.

Table 41 Climatological water balance of the year 1980 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.2	250.8	12.5	133.8	133.8	0.0	79.0
February	26.0	277.3	12.4	120.3	120.3	0.0	157.0
March	25.4	245.3	12.2	120.3	120.3	0.0	125.1
April	25.7	192.2	11.9	118.7	118.7	0.0	73.5
May	25.7	48.8	11.7	119.6	99.5	20.1	0.0
June	25.2	6.7	11.5	106.7	37.8	68.9	0.0
July	25.3	1.1	11.5	110.8	13.2	97.6	0.0
August	27.1	0.3	11.6	145.6	5.0	140.6	0.0
September	29.6	11.4	11.8	199.7	12.6	187.0	0.0
October	28.7	71.2	12.1	187.6	71.4	116.2	0.0
November	27.1	129.8	12.3	150.5	129.8	20.7	0.0
December	26.3	202.8	12.5	140.9	140.9	0.0	0.0
Annual	26.5	1437.8	144.0	1654.4	1003.3	651.1	434.5

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

Table 42 refers to BH in 1981. Annual precipitation was 1779.7 mm, evapotranspiration of 1634.4 mm, annual evaporation of 1058.1 mm, water deficit of 576.3 mm and water surplus of 721.6 mm.

Table 42 Climatological water balance of the year 1981 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.9	289.8	12.5	128.1	128.1	0.0	160.1
February	25.7	369.7	12.4	115.0	115.0	0.0	254.7
March	25.3	285.3	12.2	118.7	118.7	0.0	166.6
April	25.5	255.1	11.9	114.8	114.8	0.0	140.3
May	25.4	74.4	11.7	115.9	108.3	7.5	0.0
June	25.0	13.0	11.5	104.3	52.6	51.8	0.0
July	25.2	2.1	11.5	110.1	19.6	90.4	0.0
August	27.0	0.7	11.6	143.5	7.5	136.0	0.0
September	29.5	9.7	11.8	197.9	11.6	186.3	0.0
October	28.8	86.6	12.1	191.0	86.8	104.2	0.0
November	27.2	156.4	12.3	151.2	151.2	0.0	0.0
December	26.5	236.9	12.5	143.8	143.8	0.0	0.0
Annual	26.4	1779.7	144.0	1634.4	1058.1	576.3	721.6

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

The annual water surplus was 428.5 mm, water deficits of 692.4 mm, evaporated 1017.9 mm. It evapotranspired 1710.4 mm, with an average annual rainfall of 1446.4 mm. In the year 1982 as per (Table 43).

Table 43 Climatological water balance of the year 1982 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.2	248.8	12.5	132.3	132.3	0.0	66.1
February	26.0	279.9	12.4	119.4	119.4	0.0	160.5
March	25.4	246.8	12.2	119.3	119.3	0.0	127.5
April	25.8	193.7	11.9	119.3	119.3	0.0	74.4
May	25.8	49.3	11.7	121.5	100.7	20.8	0.0
June	25.4	6.7	11.5	108.8	37.8	71.0	0.0
July	25.4	1.1	11.5	112.8	12.9	99.9	0.0
August	27.4	0.3	11.6	151.3	4.8	146.5	0.0
September	29.8	11.7	11.8	207.3	12.8	194.4	0.0
October	29.2	72.0	12.1	201.2	72.2	129.0	0.0
November	27.6	130.4	12.3	161.2	130.4	30.8	0.0
December	27.1	205.5	12.5	156.0	156.0	0.0	0.0
Annual	26.8	1446.4	144.0	1710.4	1017.9	692.4	428.5

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

The year 1983 rained 1085.6 mm, evapotranspired 1719 mm, around 49.5% above the precipitation value. Evaporated 879.3 mm, water deficits were 879.3 mm and water surplus with an annual rate of 206.3 mm. (Table 44).

Table 44 Climatological water balance of the year 1983 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.8	190.0	12.5	144.4	144.4	0.0	0.0
February	26.6	200.0	12.4	130.5	130.5	0.0	25.8
March	26.0	310.0	12.2	129.5	129.5	0.0	180.5
April	26.1	120.2	11.9	125.4	125.3	0.1	0.0
May	26.0	0.0	11.7	124.9	67.7	57.2	0.0
June	25.6	0.0	11.5	112.7	18.4	94.3	0.0
July	25.7	0.0	11.5	116.6	6.1	110.5	0.0
August	27.5	0.0	11.6	154.0	2.2	151.9	0.0
September	29.7	0.0	11.8	204.7	0.5	204.2	0.0
October	28.7	36.2	12.1	189.5	36.3	153.2	0.0
November	27.0	78.9	12.3	147.3	78.9	68.4	0.0
December	26.3	150.3	12.5	139.6	139.6	0.0	0.0
Annual	26.8	1085.6	144.0	1719.0	879.3	839.7	206.3

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

It rained 1005 mm, evapotranspired 1620.8 mm and evaporated 743.7 mm, the water deficit recorded was 877.1 mm and the water surplus was 261.3 mm. (Table 45).

Table 45 Climatological water balance of the year 1984 for the municipality of Santa Filomena

Months	T (°C)	P (mm)	N (hora)	ETP (mm)	ETR (mm)	DEF (mm)	EXC (mm)
January	25.9	140.5	12.5	129.0	129.0	0.0	0.0
February	25.8	111.5	12.4	117.3	112.2	5.2	0.0
March	25.4	408.5	12.2	119.8	119.8	0.0	199.5
April	25.6	178.5	11.9	116.7	116.7	0.0	61.8
May	25.3	30.0	11.7	114.2	86.9	27.3	0.0
June	24.9	0.0	11.5	101.8	27.5	74.3	0.0
July	25.2	0.0	11.5	110.0	10.4	99.6	0.0
August	27.1	0.0	11.6	146.0	4.0	142.0	0.0
September	29.6	0.0	11.8	199.6	1.0	198.6	0.0
October	28.6	0.0	12.1	185.8	0.1	185.6	0.0
November	26.9	24.0	12.3	146.0	24.0	122.0	0.0
December	26.0	112.0	12.5	134.6	112.0	22.6	0.0
Annual	26.4	1005.0	144.0	1620.8	743.7	877.1	261.3

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

With a water surplus of 1665.1 mm and a deficiency of 406.9 mm, it evapotranspired 1609.2 and evaporated 1202.3 mm according to Table 46.

Table 46 Climatological water balance of the year 1985 for the municipality of Santa Filomena

Months	T (°C)	P (mm)	N (hora)	ETP (mm)	ETR (mm)	DEF (mm)	EXC (mm)
January	25.8	531.0	12.5	126.3	126.3	0.0	404.7
February	25.7	315.0	12.4	115.2	115.2	0.0	199.8
March	25.1	395.3	12.2	115.6	115.6	0.0	279.7
April	25.4	343.0	11.9	114.6	114.6	0.0	228.4
May	25.3	33.5	11.7	114.3	88.9	25.4	0.0
June	24.8	27.0	11.5	101.7	50.5	51.2	0.0
July	25.1	2.4	11.5	109.4	16.3	93.1	0.0
August	27.1	0.0	11.6	144.9	5.5	139.3	0.0
September	29.4	95.5	11.8	194.5	96.6	97.9	0.0
October	28.6	185.5	12.1	184.7	184.7	0.0	0.0
November	27.0	202.2	12.3	148.3	148.3	0.0	0.0
December	26.3	737.0	12.5	139.9	139.9	0.0	552.4
Annual	26.3	2867.4	144.0	1609.2	1202.3	406.9	1665.1

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

With annual rainfall of 1174.7 mm and evapotranspiration value of 1663.8 mm, annual evaporation of 730.7 mm and water deficiencies and surpluses of 933.1 mm and 252.2 mm, respectively, were the results of the BH of the year 1986. (Table 47).

Table 47 Climatological water balance of the year 1986 for the municipality of Santa Filomena

Months	**T**	**P**	**N**	**ETP**	**ETR**	**DEF**	**EXC**
	(°C)	**(mm)**	**(hora)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**
January	25.8	169.0	12.5	126.7	126.7	0.0	0.0
February	25.9	207.2	12.4	118.0	118.0	0.0	79.4
March	25.3	203.7	12.2	118.2	118.2	0.0	85.5
April	25.6	203.5	11.9	116.2	116.2	0.0	87.3
May	25.5	5.0	11.7	117.1	72.4	44.7	0.0
June	25.2	0.0	11.5	106.0	21.3	84.7	0.0
July	25.4	0.0	11.5	112.3	7.6	104.7	0.0
August	27.3	0.0	11.6	149.2	2.8	146.4	0.0
September	29.7	0.0	11.8	203.1	0.7	202.4	0.0
October	29.0	0.0	12.1	194.6	0.1	194.5	0.0
November	27.4	0.0	12.3	155.7	0.0	155.7	0.0
December	26.6	194.5	12.5	146.6	146.6	0.0	0.0
Annual	26.5	1174.7	144.0	1663.8	730.7	933.1	252.2

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

Table 48 corresponding to BH in 1987, where annual rainfall of 1509.1 mm was recorded, evapotranspiration and evaporation with 1766.6 mm and 1013.9 mm respectively, water deficiencies and surpluses with 752.6 and 495.2 mm.

Table 48 Climatological water balance of the year 1987 for the municipality of Santa Filomena

Months	**T**	**P**	**N**	**ETP**	**ETR**	**DEF**	**EXC**
	(°C)	**(mm)**	**(hora)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**
January	26.3	193.0	12.5	134.5	134.5	0.0	0.0
February	26.2	192.0	12.4	121.9	121.9	0.0	60.4
March	25.8	497.5	12.2	125.4	125.4	0.0	372.1
April	26.0	185.5	11.9	122.9	122.9	0.0	62.6
May	26.0	5.0	11.7	124.5	74.7	49.8	0.0
June	25.7	0.0	11.5	112.6	20.5	92.1	0.0
July	25.9	0.0	11.5	119.6	6.9	112.7	0.0
August	27.8	0.0	11.6	160.8	2.4	158.4	0.0
September	30.3	0.0	11.8	219.9	0.5	219.4	0.0
October	29.4	101.3	12.1	206.9	101.3	105.6	0.0
November	27.8	149.5	12.3	164.3	149.5	14.8	0.0
December	27.0	185.3	12.5	153.5	153.5	0.0	0.0
Annual	324.1	1509.1	144.0	1766.6	1013.9	752.6	495.2

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

Annual precipitation of 1172.8 mm, evapotranspiration and evaporation with annual values of 1644.5 and 931.4 mm and water deficiencies and surpluses totaling annual values of 713.1 mm and 241.4 mm, respectively. (Table 49).

Table 49 Climatological water balance of the year 1988 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.6	248.5	12.5	141.1	141.1	0.0	7.4
February	26.3	184.0	12.4	125.8	125.8	0.0	58.2
March	25.7	270.5	12.2	126.0	126.0	0.0	144.5
April	25.8	152.0	11.9	120.8	120.8	0.0	31.2
May	25.5	0.0	11.7	117.5	69.1	48.4	0.0
June	25.0	0.0	11.5	103.4	19.9	83.5	0.0
July	25.2	0.0	11.5	109.1	7.3	101.9	0.0
August	27.1	0.0	11.6	145.8	2.8	143.0	0.0
September	29.5	0.0	11.8	196.7	0.7	196.0	0.0
October	28.5	135.0	12.1	183.4	135.0	48.4	0.0
November	26.7	86.4	12.3	142.2	86.4	55.8	0.0
December	25.9	96.4	12.5	132.6	96.4	36.2	0.0
Annual	26.5	1172.8	144.0	1644.5	931.4	713.1	241.4

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

Table 50 shows monthly and annual precipitation fluctuations with 1121.4 mm, evapotranspiration with 1629.7 mm, evaporation with 835 mm and deficiencies and surpluses with 794.7 mm and 286.4 mm, respectively.

Table 50 Climatological water balance of the year 1989 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.6	181.6	12.5	123.8	123.8	0.0	0.0
February	25.6	215.2	12.4	113.6	113.6	0.0	59.4
March	25.1	313.1	12.2	114.6	114.6	0.0	198.5
April	25.4	142.9	11.9	114.4	114.4	0.0	28.5
May	25.4	2.0	11.7	115.6	69.9	45.7	0.0
June	25.0	0.0	11.5	103.6	20.7	82.9	0.0
July	25.3	0.0	11.5	112.1	7.7	104.4	0.0
August	27.3	0.0	11.6	148.8	2.9	145.9	0.0
September	29.6	0.0	11.8	200.0	0.7	199.3	0.0
October	28.8	38.7	12.1	190.2	38.8	151.4	0.0
November	27.1	94.7	12.3	150.8	94.7	56.1	0.0
December	26.4	133.2	12.5	142.1	133.2	8.9	0.0
Annual	26.4	1121.4	144.0	1629.7	835.0	794.7	286.4

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC) Source: Medeiros (2022).

The year 1990 was characterized according to the BH model with average annual precipitation of 598.2 mm, evapotranspiration of 1686.6 mm, evapotranspiration three times more than precipitation, evaporated 527.1 mm, with 1159.4 mm of water deficit recorded and 71.1 mm of water surplus. (Table 51).

Table 51 Climatological water balance of the year 1990for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.0	74.1	12.5	130.3	74.1	56.2	0.0
February	26.1	286.3	12.4	121.8	121.8	0.0	64.5
March	25.6	128.8	12.2	122.2	122.2	0.0	6.6
April	25.9	109.0	11.9	121.3	120.5	0.7	0.0
May	25.8	0.0	11.7	120.7	62.0	58.7	0.0
June	25.2	0.0	11.5	106.7	17.4	89.3	0.0
July	25.4	0.0	11.5	112.8	6.2	106.6	0.0
August	27.4	0.0	11.6	151.4	2.3	149.1	0.0
September	29.7	0.0	11.8	204.2	0.6	203.6	0.0
October	29.0	0.0	12.1	195.5	0.1	195.4	0.0
November	27.3	0.0	12.3	154.1	0.0	154.1	0.0
December	26.6	0.0	12.5	145.7	0.0	145.7	0.0
Annual	26.7	598.2	144.0	1686.6	527.1	1159.4	71.1

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

Annual rainfall of 834.8 mm, evapotranspiration of 1703.8 mm, evaporation of 758.9 mm and water surplus of 75.9 mm and annual water deficits of 944.9 were the conditions established by the BH in 1991. (Table 52).

Table 52 Climatological water balance of the year 1991 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.2	178.0	12.5	134.1	134.1	0.0	0.0
February	26.1	209.7	12.4	121.0	121.0	0.0	55.4
March	25.6	142.4	12.2	121.9	121.9	0.0	20.5
April	25.9	29.7	11.9	121.5	89.8	31.7	0.0
May	25.9	0.0	11.7	123.7	28.3	95.3	0.0
June	25.5	0.0	11.5	110.8	7.8	103.0	0.0
July	25.7	0.0	11.5	116.7	2.6	114.1	0.0
August	27.5	0.0	11.6	152.8	0.9	151.9	0.0
September	29.7	0.0	11.8	204.0	0.2	203.8	0.0
October	29.0	2.0	12.1	195.2	2.0	193.2	0.0
November	27.4	103.0	12.3	154.9	103.0	51.9	0.0
December	26.7	170.0	12.5	147.2	147.2	0.0	0.0
Annual	26.8	834.8	144.0	1703.8	758.9	944.9	75.9

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

BH in 1992 recorded annual rainfall of 1524.5 mm. Evapotranspired 1676.4 and evaporated 921.3 mm, water deficiencies and surpluses were 755 mm and 603.2 mm, respectively. (Table 53).

Table 53 Climatological water balance of the year 1992 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.3	544.5	12.5	134.8	134.8	0.0	409.7
February	26.2	186.0	12.4	124.0	124.0	0.0	62.0
March	25.6	107.0	12.2	124.0	122.6	1.4	0.0
April	26.0	66.0	11.9	123.3	102.8	20.5	0.0
May	25.9	13.5	11.7	124.2	45.3	78.9	0.0
June	25.3	0.0	11.5	107.9	10.4	97.5	0.0
July	25.4	0.0	11.5	113.0	3.6	109.4	0.0
August	27.2	0.0	11.6	147.1	1.3	145.8	0.0
September	29.6	22.0	11.8	199.6	22.3	177.3	0.0
October	28.7	64.5	12.1	188.8	64.5	124.3	0.0
November	27.1	320.0	12.3	149.1	149.1	0.0	71.0
December	26.3	201.0	12.5	140.4	140.4	0.0	60.6
Annual	26.6	1524.5	144.0	1676.4	921.3	755.0	603.2

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

The year 1993 represented by Table 54 registered annual rainfall of 1326 mm, evapotranspiration 1682.1 mm, evaporation 1095.2, both evapotranspiration and evaporation values were above the rainfall indexes. With a rate of 587 mm and 230.8 mm were the values of water deficiencies and surpluses.

Table 54 Climatological water balance of the year 1993 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.0	70.5	12.5	130.2	115.4	14.7	0.0
February	26.0	275.5	12.4	119.2	119.2	0.0	111.3
March	25.5	139.5	12.2	120.5	120.5	0.0	19.0
April	25.9	109.5	11.9	121.1	120.5	0.7	0.0
May	25.9	23.0	11.7	122.7	79.2	43.6	0.0
June	25.4	0.0	11.5	108.5	21.7	86.8	0.0
July	25.4	0.0	11.5	113.3	7.5	105.8	0.0
August	27.3	0.0	11.6	148.7	2.8	145.9	0.0
September	29.7	106.5	11.8	203.3	107.0	96.3	0.0
October	28.9	100.0	12.1	193.4	100.2	93.2	0.0
November	27.4	157.0	12.3	155.6	155.6	0.0	0.0
December	26.6	344.5	12.5	145.5	145.5	0.0	100.5
Annual	26.7	1326.0	144.0	1682.1	1095.2	587.0	230.8

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

Table 55 for the year 1994, mean annual rainfall of 1432.9 mm, evaporated 1056.9 mm, evapotranspiration 1682.8 mm, water deficiencies and surpluses recorded 626 and 376 mm respectively.

Table 55 Climatological water balance of the year 1994 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.2	137.0	12.5	133.4	133.4	0.0	0.0
February	26.0	301.5	12.4	119.4	119.4	0.0	148.2
March	25.5	265.2	12.2	120.5	120.5	0.0	144.7
April	25.8	202.5	11.9	119.4	119.4	0.0	83.1
May	25.7	4.5	11.7	119.4	72.8	46.6	0.0
June	25.2	2.0	11.5	106.4	22.5	83.9	0.0
July	25.3	0.0	11.5	111.7	7.5	104.2	0.0
August	27.3	0.0	11.6	149.3	2.8	146.5	0.0
September	29.6	0.0	11.8	199.9	0.7	199.2	0.0
October	29.0	150.0	12.1	195.7	150.0	45.6	0.0
November	27.5	193.2	12.3	158.2	158.2	0.0	0.0
December	26.8	177.0	12.5	149.5	149.5	0.0	0.0
Annual	26.6	1432.9	144.0	1682.8	1056.9	626.0	376.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022)

The year 1995 rained 1295.6 mm, evapotranspiration 168 3.8 mm, evaporated 1081.6 mm, water surpluses were 214 mm and water deficits were 602.2 mm in accordance with Table 56.

Table 56 Climatological water balance of the year 1995 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.4	107.5	12.5	137.9	133.7	4.2	0.0
February	26.3	143.6	12.4	125.0	125.0	0.0	0.0
March	25.7	145.0	12.2	124.4	124.4	0.0	13.0
April	25.8	157.5	11.9	120.7	120.7	0.0	36.8
May	25.8	100.5	11.7	120.7	118.8	1.9	0.0
June	25.4	0.0	11.5	109.4	54.4	55.1	0.0
July	25.6	0.0	11.5	115.5	18.7	96.7	0.0
August	27.3	0.0	11.6	150.1	6.7	143.4	0.0
September	29.6	0.0	11.8	201.1	1.7	199.4	0.0
October	28.8	88.0	12.1	189.6	88.2	101.5	0.0
November	27.1	284.0	12.3	149.6	149.6	0.0	34.5
December	26.3	269.5	12.5	139.7	139.7	0.0	129.8
Annual	26.7	1295.6	144.0	1683.8	1081.6	602.2	214.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022)

It rained 1215 mm, evapotranspired 1657.3 mm, evaporated 1024.2 mm, with a water surplus of 190.8 mm and water deficiencies of 633 mm, according to Table 57, for the year 1996.

Table 57 Climatological water balance of the year 1996 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.0	181.0	12.5	130.2	130.2	0.0	3.3
February	25.9	153.5	12.4	118.7	118.7	0.0	34.8
March	25.4	189.5	12.2	120.6	120.6	0.0	68.9
April	25.7	202.0	11.9	118.2	118.2	0.0	83.8
May	25.6	83.5	11.7	117.8	112.6	5.3	0.0
June	25.2	0.0	11.5	106.9	46.6	60.3	0.0
July	25.4	0.0	11.5	113.6	16.5	97.0	0.0
August	27.3	0.0	11.6	150.3	6.1	144.2	0.0
September	29.7	0.0	11.8	201.7	1.5	200.2	0.0
October	28.8	64.0	12.1	190.3	64.2	126.2	0.0
November	27.1	171.0	12.3	149.8	149.8	0.0	0.0
December	26.3	170.5	12.5	139.3	139.3	0.0	0.0
Annual	26.5	1215.0	144.0	1657.3	1024.2	633.2	190.8

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022)

It rained 1433.7 mm, evaporated 979 mm, evapotranspired 1762.4 mm, water deficits were 783.5 mm and water surpluses were 454.7 mm for the year 1997 (Table 58).

Table 58 Climatological water balance of the year 1997 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.9	368.7	12.5	126.8	126.8	0.0	162.8
February	25.8	111.5	12.4	115.9	115.8	0.1	0.0
March	25.4	412.0	12.2	118.7	118.7	0.0	289.0
April	25.8	122.5	11.9	119.5	119.5	0.0	3.0
May	25.9	12.5	11.7	121.8	79.0	42.9	0.0
June	25.6	0.0	11.5	111.5	22.5	89.0	0.0
July	25.9	0.0	11.5	119.9	7.7	112.2	0.0
August	27.9	0.0	11.6	161.5	2.7	158.8	0.0
September	30.3	0.0	11.8	220.2	0.6	219.6	0.0
October	29.6	78.0	12.1	212.6	78.1	134.5	0.0
November	28.1	144.5	12.3	170.9	144.5	26.3	0.0
December	27.4	184.0	12.5	163.1	163.1	0.0	0.0
Annual	323.5	1433.7	144.0	1762.4	979.0	783.5	454.7

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022)

The year 1998 registered rainfall of 882.1 mm, evapotranspiration was practically twice the amount of precipitation (ETP of 1760.5 mmano-1), evaporated 908.4 mm, there was no water surplus and water deficiencies were 852 .1 mm according to Table 59.

Table 59 Climatological water balance of the year 1998 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	27.1	128.0	12.5	150.8	162.1	11.3	0.0
February	27.0	125.5	12.4	136.7	132.5	4.2	0.0
March	26.3	144.1	12.2	135.0	135.0	0.0	0.0
April	26.4	15.5	11.9	130.6	62.0	68.5	0.0
May	26.3	0.0	11.7	130.0	15.7	114.3	0.0
June	25.7	0.0	11.5	112.3	4.0	108.4	0.0
July	25.8	0.0	11.5	117.9	1.3	116.6	0.0
August	27.6	0.0	11.6	155.2	0.5	154.7	0.0
September	29.9	0.0	11.8	208.8	0.1	208.7	0.0
October	28.9	106.5	12.1	194.5	106.5	88.0	0.0
November	27.2	174.5	12.3	151.0	151.0	0.0	0.0
December	26.3	188.0	12.5	137.8	137.8	0.0	0.0
Annual	324.3	882.1	144.0	1760.5	908.4	852.1	0.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022)

With annual rainfall of 1027.7 mm, 801.7 mm evaporated, evapotranspired 1618.4 mm, water surpluses and water deficiencies were 226 mm and 816.7 mm for the year 1999 (Table 60).

Table 60 Climatological water balance of the year 1999 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.9	212.0	12.5	127.9	127.9	0.0	84.1
February	25.8	178.5	12.4	117.2	117.2	0.0	61.3
March	25.4	199.2	12.2	119.8	119.8	0.0	79.4
April	25.4	102.5	11.9	114.9	114.2	0.7	0.0
May	25.4	20.0	11.7	115.6	74.4	41.2	0.0
June	25.0	0.0	11.5	103.8	21.9	81.8	0.0
July	25.3	0.0	11.5	111.3	8.1	103.2	0.0
August	27.1	0.0	11.6	146.0	3.0	143.0	0.0
September	29.4	0.0	11.8	194.9	0.8	194.1	0.0
October	28.6	0.0	12.1	184.6	0.1	184.5	0.0
November	26.9	77.0	12.3	145.2	77.0	68.2	0.0
December	26.1	238.5	12.5	137.3	137.3	0.0	1.2
Annual	26.3	1027.7	144.0	1618.4	801.7	816.7	226.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022)

With a water surplus totaling 381.2 mm, water deficits of 758.8 mm, evaporated 808.8 mm, evapotranspired 1639.6 mm and annual rainfall of 1262 mm according to Table 61 for the year 2000.

Table 61 Climatological water balance of the year 2000 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.7	333.0	12.5	125.6	125.6	0.0	116.8
February	25.7	267.0	12.4	115.4	115.4	0.0	151.6
March	25.2	133.0	12.2	117.1	117.1	0.0	15.9
April	25.6	214.5	11.9	117.6	117.6	0.0	96.9
May	25.5	50.0	11.7	117.6	99.2	18.5	0.0
June	25.0	0.0	11.5	104.1	32.9	71.2	0.0
July	25.3	0.0	11.5	111.3	12.1	99.2	0.0
August	27.3	0.0	11.6	149.1	4.6	144.5	0.0
September	29.6	6.2	11.8	200.5	7.3	193.2	0.0
October	28.8	28.3	12.1	190.1	28.5	161.7	0.0
November	27.1	80.0	12.3	150.6	80.0	70.5	0.0
December	26.3	150.0	12.5	140.6	140.6	0.0	0.0
Annual	26.4	1262.0	144.0	1639.6	880.8	758.8	381.2

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

995.5 mm was the total rainfall recorded in 2001, the value of evapotranspiration was 1681.6 mm, with a total of 901.4 mm evaporated and 780.1 mm of water deficit with 94.1 mm of surplus water (Table 62).

Table 62 Climatological water balance of the year 2001 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.0	209.7	12.5	128.9	128.9	0.0	0.0
February	25.9	222.2	12.4	118.5	118.5	0.0	84.5
March	25.6	132.6	12.2	123.0	123.0	0.0	9.6
April	25.9	100.6	11.9	121.0	119.0	1.9	0.0
May	25.7	84.5	11.7	120.3	109.0	11.2	0.0
June	25.3	0.0	11.5	108.2	37.7	70.5	0.0
July	25.5	0.0	11.5	114.4	13.2	101.2	0.0
August	27.4	0.0	11.6	151.2	4.8	146.4	0.0
September	29.8	10.0	11.8	204.8	11.2	193.7	0.0
October	29.0	46.0	12.1	195.1	46.1	149.0	0.0
November	27.3	89.0	12.3	152.8	89.0	63.8	0.0
December	26.5	100.9	12.5	143.3	100.9	42.4	0.0
Annual	26.6	995.5	144.0	1681.6	901.4	780.1	94.1

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

With 1477.5 mm of precipitation, 1734.2 mm of evapotranspiration, and evaporative power of 854.2 mm, the water deficits and surpluses of 879.9 mm and 623.2 mm, respectively, were the results of the BH in 2002. (Table 63).

Table 63 Climatological water balance of the year 2002 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.2	569.5	12.5	132.5	132.5	0.0	414.4
February	26.1	273.0	12.4	120.8	120.8	0.0	152.2
March	25.7	180.5	12.2	123.8	123.8	0.0	56.7
April	26.0	83.5	11.9	122.7	116.0	6.8	0.0
May	25.9	0.0	11.7	122.7	47.7	75.0	0.0
June	25.5	0.0	11.5	110.8	13.3	97.6	0.0
July	25.7	0.0	11.5	116.7	4.5	112.2	0.0
August	27.6	0.0	11.6	155.1	1.6	153.5	0.0
September	29.9	41.0	11.8	210.5	41.4	169.2	0.0
October	29.2	14.5	12.1	202.1	14.6	187.5	0.0
November	27.7	84.0	12.3	162.3	84.0	78.3	0.0
December	27.0	231.5	12.5	154.0	154.0	0.0	0.0
Annual	26.9	1477.5	144.0	1734.2	854.2	879.9	623.3

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

With annual rainfall of 795.5 mm, evapotranspiration of 1735.2 mm, annual evaporation of 589.2 mm, annual water deficit of 1146 mm and water surplus of 206.3 mm (Table 64).

Table 64 Climatological water balance of the year 2003 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.5	258.5	12.5	139.1	139.1	0.0	19.4
February	26.4	143.5	12.4	125.9	125.9	0.0	17.6
March	25.8	296.0	12.2	126.7	126.7	0.0	169.3
April	26.0	90.0	11.9	122.7	117.9	4.8	0.0
May	25.7	0.0	11.7	118.5	50.1	68.5	0.0
June	25.3	0.0	11.5	107.2	14.5	92.7	0.0
July	25.6	0.0	11.5	115.8	5.2	110.6	0.0
August	27.6	0.0	11.6	155.1	1.9	153.2	0.0
September	30.0	0.0	11.8	211.6	0.4	211.2	0.0
October	29.2	7.5	12.1	202.6	7.6	195.1	0.0
November	27.6	0.0	12.3	160.3	0.0	160.2	0.0
December	26.8	0.0	12.5	149.6	0.0	149.6	0.0
Annual	26.9	795.5	144.0	1735.2	589.2	1146.0	206.3

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

In Table 65, corresponding to the year 2004, annual rainfall of 963.8 mm was recorded, with evapotranspiration of 1722.5 mm and 963.8 mm evaporated. Water deficit of 758.7 mm and no water surpluses.

Table 65 Climatological water balance of the year 2004 for the municipality of Santa Filomena

Months	**T**	**P**	**N**	**ETP**	**ETR**	**DEF**	**EXC**
	(°C)	**(mm)**	**(hora)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**
January	26.5	141.1	12.5	139.1	139.1	0.0	0.0
February	26.3	137.4	12.4	124.6	124.6	0.0	0.0
March	25.6	137.6	12.2	123.3	123.3	0.0	0.0
April	25.9	124.1	11.9	121.8	121.8	0.0	0.0
May	25.7	67.3	11.7	118.8	79.9	38.9	0.0
June	25.2	18.5	11.5	105.3	29.3	76.0	0.0
July	25.4	4.9	11.5	112.7	10.0	102.7	0.0
August	27.4	1.6	11.6	151.7	3.7	148.0	0.0
September	30.0	25.9	11.8	211.3	26.4	184.9	0.0
October	29.2	75.9	12.1	200.3	76.0	124.3	0.0
November	27.6	92.0	12.3	160.7	92.0	68.8	0.0
December	26.9	137.6	12.5	152.8	137.6	15.2	0.0
Annual	26.8	963.8	144.0	1722.5	963.8	758.7	0.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022)

In 2005, it rained 706.8 mm, evaporated 646.5 mm and evapotranspired 1715.5 mm, with a water deficit of 1069 mm and a water surplus of 60.3 mm (Table 66).

Table 66 Climatological water balance of the year 2005 for the municipality of Santa Filomena

Months	**T**	**P**	**N**	**ETP**	**ETR**	**DEF**	**EXC**
	(°C)	**(mm)**	**(hora)**	**(mm)**	**(mm)**	**(mm)**	**(mm)**
January	26.5	299.8	12.5	139.5	139.5	0.0	60.3
February	26.3	65.0	12.4	125.0	110.1	14.9	0.0
March	25.8	138.0	12.2	126.4	126.4	0.0	0.0
April	26.0	58.0	11.9	123.2	89.8	33.3	0.0
May	25.9	0.0	11.7	123.1	24.6	98.6	0.0
June	25.4	0.0	11.5	108.9	6.7	102.2	0.0
July	25.6	0.0	11.5	115.5	2.3	113.2	0.0
August	27.6	0.0	11.6	154.7	0.8	153.8	0.0
September	29.8	0.0	11.8	207.2	0.2	207.0	0.0
October	29.0	20.0	12.1	197.1	20.0	177.1	0.0
November	27.3	76.0	12.3	152.6	76.0	76.6	0.0
December	26.4	50.0	12.5	142.2	50.0	92.2	0.0
Annual	321.7	706.8	144.0	1715.5	646.5	1069.0	60.3

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022)

Table 67, corresponding to the BH in 2006, annual rainfall of 1437.8 mm was recorded, 1720.6 mm evapotranspired, with a total of 1012.1 mm evaporated, the water surplus of 708.5 mm and 425.7 mm of surplus was the characterization of the year 2006**.**

Table 67 Climatological water balance of the year 2006 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.0	250.8	12.5	129.7	129.7	0.0	69.4
February	26.0	277.3	12.4	119.4	119.4	0.0	157.8
March	25.5	245.3	12.2	120.1	120.1	0.0	125.3
April	25.8	192.2	11.9	119.0	119.0	0.0	73.2
May	25.8	48.8	11.7	121.5	100.5	21.0	0.0
June	25.4	6.7	11.5	109.4	37.7	71.7	0.0
July	25.6	1.1	11.5	115.3	12.9	102.5	0.0
August	27.6	0.3	11.6	155.6	4.7	150.9	0.0
September	30.0	11.4	11.8	212.0	12.4	199.6	0.0
October	29.2	71.2	12.1	201.6	71.3	130.3	0.0
November	27.7	129.8	12.3	162.3	129.8	32.5	0.0
December	27.0	202.8	12.5	154.6	154.6	0.0	0.0
Annual	26.8	1437.8	144.0	1720.6	1012.1	708.5	425.7

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

667 mm of precipitation, 1667.4 mm of evapotranspiration, 442.8 mm of water deficiencies and surpluses evaporated with 1224.6 mm and 224.2 mm respectively for the year 2007 (Table 68).

Table 68 Climatological water balance of the year 2007 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.5	164.0	12.5	140.4	140.4	0.0	0.0
February	26.3	426.0	12.4	125.4	125.4	0.0	224.2
March	25.6	0.0	12.2	123.8	71.0	52.8	0.0
April	25.9	0.0	11.9	121.8	20.4	101.4	0.0
May	25.7	15.0	11.7	120.1	20.6	99.5	0.0
June	25.4	0.0	11.5	108.7	2.0	106.7	0.0
July	25.4	0.0	11.5	113.4	0.7	112.7	0.0
August	27.3	0.0	11.6	149.0	0.3	148.7	0.0
September	29.5	0.0	11.8	198.7	0.1	198.6	0.0
October	28.6	0.0	12.1	186.0	0.0	186.0	0.0
November	26.8	62.0	12.3	144.0	62.0	82.0	0.0
December	26.1	0.0	12.5	136.2	0.0	136.2	0.0
Annual	26.6	667.0	144.0	1667.4	442.8	1224.6	224.2

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022)

Evapotranspired and evaporated 1656.7 mm and 629.9 mm respectively, with annual rainfall of 793 mm, deficiencies of 1026.8 mm and water surpluses of 163.1 mm (Table 69).

Table 69 Climatological water balance of the year2008 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.7	103.5	12.5	124.7	103.5	21.2	0.0
February	25.6	377.0	12.4	113.9	113.9	0.0	163.1
March	25.2	87.0	12.2	117.1	113.0	4.1	0.0
April	25.5	127.5	11.9	115.2	115.2	0.0	0.0
May	25.5	0.0	11.7	116.4	59.3	57.0	0.0
June	25.1	0.0	11.5	105.5	17.6	87.9	0.0
July	25.5	0.0	11.5	114.2	6.4	107.8	0.0
August	27.5	0.0	11.6	153.4	2.4	151.0	0.0
September	29.8	0.0	11.8	206.0	0.6	205.4	0.0
October	29.0	0.0	12.1	195.3	0.1	195.2	0.0
November	27.2	0.0	12.3	152.6	0.0	152.5	0.0
December	26.4	98.0	12.5	142.6	98.0	44.6	0.0
Annual	26.5	793.0	144.0	1656.7	629.9	1026.8	163.1

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

In 2009, annual rainfall of 1444.4 mm was recorded, evapotranspiration was 1735.4 mm, evaporation of 1138.8 mm and water deficits with 596.5 mm, the water surplus totaled 305.6 mm (Table 70).

Table 70 Climatological water balance of the year 2009 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.0	139.5	12.5	129.3	129.3	0.0	0.0
February	25.9	117.5	12.4	117.5	117.5	0.0	0.0
March	25.4	67.9	12.2	118.9	107.1	11.8	0.0
April	25.8	384.0	11.9	119.3	119.3	0.0	223.7
May	25.9	205.0	11.7	123.1	123.1	0.0	81.9
June	25.6	0.0	11.5	112.4	67.5	44.9	0.0
July	25.8	0.0	11.5	119.0	22.6	96.4	0.0
August	27.8	0.0	11.6	159.2	7.9	151.4	0.0
September	30.1	25.5	11.8	213.8	27.2	186.6	0.0
October	29.3	189.5	12.1	205.0	189.5	15.5	0.0
November	27.7	72.5	12.3	162.7	72.7	90.1	0.0
December	27.1	243.0	12.5	155.1	155.1	0.0	0.0
Annual	26.9	1444.4	144.0	1735.4	1138.8	596.5	305.6

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022)

With a total annual rainfall of 1048.7 mm, evapotranspired 1698.8 mm, evaporated 967.9 mm, water surpluses were 80.8 mm, water deficiencies totaled 730.8 mm, in accordance with Table 71 for the year 2010.

Table 71 Climatological water balance of the year 2010 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.7	80.0	12.5	142.7	111.4	31.3	0.0
February	26.5	120.0	12.4	129.2	123.2	6.0	0.0
March	26.1	165.0	12.2	131.5	131.5	0.0	0.0
April	26.3	244.0	11.9	129.6	129.6	0.0	80.8
May	26.1	25.0	11.7	126.1	88.6	37.5	0.0
June	25.5	0.0	11.5	110.8	24.4	86.4	0.0
July	25.5	0.0	11.5	114.0	8.2	105.8	0.0
August	27.2	0.0	11.6	148.2	3.0	145.2	0.0
September	29.5	11.1	11.8	199.1	11.9	187.2	0.0
October	28.6	69.2	12.1	186.1	69.3	116.8	0.0
November	26.9	131.5	12.3	146.2	131.5	14.6	0.0
December	26.1	202.9	12.5	135.5	135.5	0.0	0.0
Annual	26.8	1048.7	144.0	1698.8	967.9	730.8	80.8

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022)

The BH result for 2011 is shown in Table 67, where there was no water surplus, water deficiencies totaled 800.1 mm, 892.4 mm evaporated, equal to the total rainfall. Evapotranspiration above the rainfall levels. (Table 72).

Table 72 Climatological water balance of the year 2011 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	mm)	(mm)	(mm)
January	26.2	129.8	12.5	133.5	129.8	3.7	0.0
February	26.1	133.2	12.4	121.5	121.5	0.0	0.0
March	25.6	127.3	12.2	122.6	122.6	0.0	0.0
April	25.9	115.6	11.9	120.9	116.5	4.5	0.0
May	25.8	61.6	11.7	120.9	68.5	52.4	0.0
June	25.3	16.7	11.5	108.1	21.9	86.2	0.0
July	25.5	4.4	11.5	114.4	6.7	107.7	0.0
August	27.4	1.5	11.6	151.8	2.3	149.5	0.0
September	29.8	23.3	11.8	205.0	23.5	181.5	0.0
October	29.0	68.1	12.1	194.8	68.1	126.7	0.0
November	27.3	83.9	12.3	154.0	83.9	70.2	0.0
December	26.6	127.0	12.5	144.8	127.0	17.8	0.0
Annual	26.7	892.4	144.0	1692.5	892.4	800.1	0.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

Table 73 shows the distribution of the representative climatological water balance of the year 2012, which recorded rainfall of 603.1 mm, evapotranspiration above the rainfall values (1630.5), evaporated 603.1 mm equal to the rainfall value, there was a deficiency water flow of 1027.4 mm and there was no water surplus.

Table 73 Climatological water balance of the year 2012 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	25.9	99.0	12.5	129.2	99.0	30.2	0.0
February	25.8	105.0	12.4	117.6	105.0	12.6	0.0
March	25.3	110.0	12.2	118.3	110.0	8.3	0.0
April	25.5	120.0	11.9	116.4	116.4	0.0	0.0
May	25.5	35.0	11.7	116.3	37.0	79.3	0.0
June	25.0	9.1	11.5	104.3	10.1	94.2	0.0
July	25.2	0.0	11.5	110.7	0.4	110.3	0.0
August	27.1	0.0	11.6	146.2	0.2	146.0	0.0
September	29.5	0.0	11.8	196.6	0.0	196.6	0.0
October	28.7	0.0	12.1	187.0	0.0	187.0	0.0
November	27.0	50.0	12.3	148.3	50.0	98.3	0.0
December	26.3	75.0	12.5	139.6	75.0	64.6	0.0
Annual	26.4	603.1	144.0	1630.5	603.1	1027.4	0.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

With pluviometric values equal to the evaporated values, and evapotranspiration above the rain values, there was no excess and the deficiencies totaled 1015.5 mm. (Table 74).

Table 74 Climatological water balance of the year 2013 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.0	105.0	12.5	130.2	105.0	25.2	0.0
February	25.9	99.0	12.4	118.6	99.0	19.6	0.0
March	25.4	121.1	12.2	119.5	119.5	0.0	0.0
April	25.6	102.9	11.9	117.7	103.1	14.6	0.0
May	25.5	22.2	11.7	117.5	23.1	94.5	0.0
June	25.1	0.0	11.5	105.2	0.3	104.9	0.0
July	25.3	0.0	11.5	111.4	0.1	111.3	0.0
August	27.2	0.0	11.6	147.6	0.0	147.5	0.0
September	29.5	0.0	11.8	198.3	0.0	198.3	0.0
October	28.7	0.0	12.1	188.6	0.0	188.6	0.0
November	27.1	79.2	12.3	149.5	79.2	70.3	0.0
December	26.3	100.1	12.5	140.9	100.1	40.8	0.0
Annual	26.5	629.5	144.0	1645.0	629.5	1015.5	0.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

Table 75 shows the fluctuations of the BH corresponding to the year 2014, it rained 620 mm, evapotranspired one and a half times above the rainfall, evaporated the same amount of rain recorded, with a water surplus of 1025 mm and there were no surpluses.

Table 75 Climatological water balance of the year 2014 for the municipality of Santa Filomena

Months	T (°C)	P (mm)	N (hora)	ETP (mm)	ETR (mm)	DEF (mm)	EXC (mm)
January	26.0	100.3	12.5	130.2	100.3	29.9	0.0
February	25.9	123.5	12.4	118.6	118.6	0.0	0.0
March	25.4	92.1	12.2	119.5	93.3	26.2	0.0
April	25.6	100.1	11.9	117.7	100.7	17.0	0.0
May	25.5	22.7	11.7	117.5	24.6	92.9	0.0
June	25.1	0.0	11.5	105.2	0.8	104.4	0.0
July	25.3	0.0	11.5	111.4	0.3	111.1	0.0
August	27.2	0.0	11.6	147.6	0.1	147.5	0.0
September	29.5	0.0	11.8	198.3	0.0	198.3	0.0
October	28.7	15.0	12.1	188.6	15.0	173.6	0.0
November	27.1	66.8	12.3	149.5	66.8	82.7	0.0
December	26.3	99.5	12.5	140.9	99.5	41.4	0.0
Annual	26.5	620.0	144.0	1645.0	620.0	1025.0	0.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC); Source: Medeiros (2022).

The year 2015 registered a rainfall of 700.5 mm, evapotranspired 1709.7 practically once more than the rainfall, evaporating equal to the rainfall index, the water deficiencies recorded were 1009.2 mm and there were no water surpluses. (Table 76).

Table 76 Climatological water balance of the year 2015 for the municipality of Santa Filomena

Months	T (°C)	P (mm)	N (hora)	ETP (mm)	ETR (mm)	DEF (mm)	EXC (mm)
January	26.3	95.8	12.5	135.1	95.8	39.3	0.0
February	26.2	192.1	12.4	123.0	123.0	0.0	0.0
March	25.7	73.4	12.2	123.8	100.8	23.0	0.0
April	25.9	114.8	11.9	122.0	117.7	4.3	0.0
May	25.8	32.2	11.7	121.8	55.2	66.6	0.0
June	25.4	1.7	11.5	108.9	12.1	96.8	0.0
July	25.6	0.4	11.5	115.4	4.1	111.3	0.0
August	27.5	0.1	11.6	153.5	1.5	152.0	0.0
September	29.8	4.6	11.8	207.4	4.9	202.6	0.0
October	29.0	35.6	12.1	196.9	35.6	161.3	0.0
November	27.4	58.1	12.3	155.5	58.1	97.4	0.0
December	26.6	91.8	12.5	146.3	91.8	54.5	0.0
Annual	26.8	700.5	144.0	1709.7	700.5	1009.2	0.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC). Source: Medeiros (2022)

With annual rainfall of 842.7 mm, evapotranspiration of 1665.6 mm twice the amount of rainfall and evaporation practically equal to rainfall, the water deficit of 854.4 mm surpassing the rainfall index and with only 31.5 mm of surplus occurring in the month of February according to Table 77, corresponding to the year 2016.

Table 77 Climatological water balance of the year 2016 for the municipality of Santa Filomena

Months	T (°C)	P (mm)	N (hora)	ETP (mm)	ETR (mm)	DEF (mm)	EXC (mm)
January	25.9	116.7	12.5	128.2	116.7	11.5	0.0
February	26.2	255.1	12.4	123.6	123.6	0.0	31.5
March	25.7	107.1	12.2	125.2	123.7	1.5	0.0
April	25.4	121.6	11.9	113.4	113.4	0.0	0.0
May	25.6	30.8	11.7	118.3	84.2	34.1	0.0
June	25.3	8.4	11.5	107.9	32.4	75.5	0.0
July	25.4	2.2	11.5	112.8	11.6	101.2	0.0
August	27.4	0.7	11.6	151.7	4.4	147.3	0.0
September	29.6	11.6	11.8	200.1	12.5	187.6	0.0
October	28.8	34.0	12.1	190.6	34.2	156.4	0.0
November	27.2	41.9	12.3	151.8	41.9	109.8	0.0
December	26.4	112.5	12.5	142.0	112.5	29.5	0.0
Annual	26.6	842.7	144.0	1665.6	811.2	854.4	31.5

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC). Source: Medeiros (2022).

Table 78 Climatological water balance of the year 2017 for the municipality of Santa Filomena

Months	T (°C)	P (mm)	N (hora)	ETP (mm)	ETR (mm)	DEF (mm)	EXC (mm)
January	26.1	118.4	12.5	132.1	118.8	13.3	0.0
February	26.0	159.2	12.4	120.3	120.3	0.0	0.0
March	25.3	95.0	12.2	118.3	103.7	14.6	0.0
April	25.3	208.5	11.9	112.0	112.0	0.0	29.6
May	25.6	90.3	11.7	118.5	114.9	3.6	0.0
June	25.2	0.0	11.5	106.5	49.4	57.1	0.0
July	25.4	0.0	11.5	113.1	17.6	95.5	0.0
August	27.5	0.0	11.6	153.8	6.6	147.2	0.0
September	29.4	0.0	11.8	194.8	1.5	193.3	0.0
October	28.8	74.5	12.1	190.4	74.7	115.7	0.0
November	27.2	54.8	12.3	151.8	54.9	97.0	0.0
December	26.3	143.5	12.5	140.2	140.2	0.0	0.0
Annual	26.5	944.2	144.0	1651.9	914.6	737.4	29.6

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC). Source: Medeiros (2022).

Table 79 Climatological water balance of the year 1960- 2017 for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	26.0	234.4	12.5	130.2	130.2	0.0	55.2
February	25.9	263.8	12.4	118.8	118.8	0.0	145.1
March	25.4	225.9	12.2	119.6	119.6	0.0	106.3
April	25.6	185.3	11.9	117.6	117.6	0.0	67.7
May	25.5	48.4	11.7	117.6	98.4	19.3	0.0
June	25.1	6.6	11.5	105.3	38.0	67.3	0.0
July	25.3	1.1	11.5	111.5	13.6	98.0	0.0
August	27.2	0.3	11.6	147.8	5.1	142.7	0.0
September	29.5	10.7	11.8	198.4	11.9	186.5	0.0
October	28.7	66.8	12.1	188.8	67.0	121.8	0.0
November	27.1	122.1	12.3	149.7	122.1	27.5	0.0
December	26.3	192.0	12.5	141.0	141.0	0.0	0.0
Annual	26.5	1174.7	144.0	1646.4	983.3	663.2	374.3

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC). Source: Medeiros (2022)

Table 80 Climatological water balance with 1 °C increase in temperature and 10% reduction in precipitation for the municipality of Santa Filomena

Months	T	P	N	ETP	ETR	DEF	EXC
	(°C)	(mm)	(hora)	(mm)	(mm)	(mm)	(mm)
January	27.0	210.9	12.5	147.9	147.9	0.0	0.0
February	26.9	237.5	12.4	134.7	134.7	0.0	78.1
March	26.4	203.3	12.2	135.1	135.1	0.0	68.2
April	26.6	166.8	11.9	133.1	133.1	0.0	33.7
May	26.5	43.6	11.7	133.0	102.7	30.3	0.0
June	26.1	5.9	11.5	118.7	33.6	85.1	0.0
July	26.3	1.0	11.5	125.9	10.4	115.5	0.0
August	28.2	0.3	11.6	169.5	3.4	166.1	0.0
September	30.5	9.6	11.8	231.8	10.3	221.6	0.0
October	29.7	60.2	12.1	219.1	60.2	158.9	0.0
November	28.1	109.9	12.3	171.4	109.9	61.5	0.0
December	27.3	172.8	12.5	160.5	160.5	0.0	0.0
Annual	27.5	1221.8	144.0	1880.8	1041.8	839.0	180.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC). Source: Medeiros (2022)

The year 2017 presented annual precipitation of 944.2 mm, evapotranspiration of 1651.9 mm, evapotranspiration 65% above the value of precipitation and evaporating 914.6 mm in relation to precipitation, the gain was 27.6 mm. The water surplus was only 29.6 mm and the water deficits were 737.4 mm, as shown in Table 78.

The calculation of the BHC for the period 1960-2017 is represented in Table 79, which recorded 1174.7 mm of annual precipitation, the evapotranspiration and evaporation indices were 1646.4 mm and 983.3 mm respectively, water deficiencies and surpluses have the values of 663.2 mm and 374.3 mm.

Table 80 shows the representativeness of the water balance with a 1 °C increase in temperature and a 10% reduction in precipitation. The annual precipitation will be 1221.8 mm, the registered annual evapotranspiration will be 1880.8 mm and the evaporated indices of 1041.8 mm, the water surpluses and deficiencies will be 839 mm and 180 mm respectively.

The water balance with a 4 °C increase in temperature and a 20% reduction in precipitation will present an annual rainfall of 1086.1 mm at the rates of evapotranspiration and evaporation will be 3042.3 mm and 1086.1 mm, the water deficiencies recorded if with 1956.3 mm and water surpluses will not occur, according to the results of Table 81.

Table 81 Climatological water balance with a 4°C increase in temperature and a 20% reduction in precipitation for the municipality of Santa Filomena

Months	T (°C)	P (mm)	N (hora)	ETP (mm)	ETR (mm)	DEF (mm)	EXC (mm)
January	30.0	187.5	12.5	233.4	187.5	45.9	0.0
February	29.9	211.1	12.4	212.0	211.1	0.9	0.0
March	29.4	180.7	12.2	209.1	180.7	28.4	0.0
April	29.6	148.3	11.9	207.7	148.3	59.4	0.0
May	29.5	38.7	11.7	207.0	38.7	168.3	0.0
June	29.1	5.3	11.5	182.3	5.3	177.0	0.0
July	29.3	0.9	11.5	194.4	0.9	193.5	0.0
August	31.2	0.3	11.6	277.6	0.3	277.3	0.0
September	33.5	8.6	11.8	407.2	8.6	398.6	0.0
October	32.7	53.5	12.1	375.9	53.5	322.4	0.0
November	31.1	97.7	12.3	279.9	97.7	182.2	0.0
December	30.3	153.6	12.5	255.9	153.6	102.3	0.0
Annual	30.5	1086.1	144.0	3042.3	1086.1	1956.3	0.0

Legend: Average air temperature (T), Precipitation (P), Photoperiod (N), Potential Evapotranspiration (ETP), Actual Evaporation (ETR), Water Deficiency (DEF) and Water Excess (EXC). Source: Medeiros (2022).

4. Conclusion

In the studied area, a "tipping point" was found in the distribution of precipitation. Consecutive dry years were observed; however, after these years, there was a reduction in the frequency of dry years and an increase in the severity of the events.

The calculation of the water balance for the period 1960-2017 shows a scenario of changes in the rainfall regime, the pre-season rains and the beginning of the characterization of the period had moderate to heavy rainfall in short time intervals and with a predominance of strong summers in the development of the rainy season, there is a reduction in rainfall.

The physiographic aspects, relief, fauna, flora and distance from the sea are evidenced and the edaphic contributions contribute to the incidence of aridity index and susceptibility to desertification in the studied area.

In past decades, disproportionate deforestation in large areas, lack of soil cover outside the planting season, high rates of fires and fire outbreaks, have contributed to the beginnings of aridity and the beginnings of desertification.

Another high-consistency contributor is the incidences of adverse and short-term phenomena that constantly occur in the study area.

The development of monoculture and improper planting techniques contributed to the increase in erosion rates and the tendency for changes in semi-arid climates with very high risk of susceptibility.

Areas identified as vulnerable to desertification, due to the lower aridity index, may not be located in the degraded área, and areas that present a higher aridity index and are not identified as vulnerability processes may be degraded to the point of being considered desertified areas. This variability may occur due to inappropriate use of the soil and environment. The period from 1960 to 2017 was studied in order to determine with greater certainty the data on susceptibility levels and climate classifications with greater precision to determine the existence or not of areas with desertification. In this sense, the greater the precipitation, the greater the aridity index, and in the face of desertification, the lower the susceptibility.

The aridity index calculated in the water balance shows wide interannual and intermunicipal spatial oscillation, however the aridity indexes are above the values established for desertification.

Temperature influences evapotranspiration, that is, the loss of water to the atmosphere, because the higher the temperature, the greater the evapotranspiration and. Consequently, the lower the aridity index and. Therefore, the greater the susceptibility to desertification.

The spatial distribution of rainfall occurs irregularly and with high monthly and annual variability. as well as the distribution of annual temperature, making the semi-arid climate predominate in most of the years studied.

Information on the climatic conditions of a particular region is necessary so that strategies can be instituted, aimed at the most appropriate management of natural resources. Thus planning the search for sustainable development for the implementation of viable and safe agricultural practices for the environment, and agricultural productivity in the studied area.

The probabilities of rain at 25%. 50% and 75% show that in the months of June to September the lowest rainfall rates are recorded and between the months of November to April the highest rainfall rates are recorded. With a 25% probability of rain, agriculture must have adequate planning for its subsistence.

The results of evapotranspiration are in agreement with several studies carried out for the semi-arid region of Northeast Brazil and especially in the state of Piauí. This trend is a reflection of the spatial variation of the monthly mean air temperature in the study area.

Possibly anthropic factors, the lack of afforestation in the beds of ponds, lakes, rivers, streams, streams, dams and water tables, the vertical construction and compaction of urban and rural soil plus transient meteorological systems and local factors may have contributed to periods (months, years) with greater variability, however it is known that depending on the season, summer or winter, the ETP and EVR can really vary, as they are directly related to the seasons with greater and lesser precipitation, variability in air temperature, air humidity between other variables such as solar radiation, cloud cover, wind speed and vapor saturation pressure, which can reduce the evaporative process.

With an increase in temperature and a reduction in precipitation, water deficiencies do not increase and cause greater wear on the levels of dams, dams, agribusiness, agriculture and livestock among many other areas. The population will have to resort to rainwater storage on a daily basis, in the agricultural sector it will have to plant with seeds that are resistant to low rainfall.

The afternoons are getting warm and the dawns are cold, the thermal amplitudes can cause increases in respiratory diseases in newborns and the elderly. In the agricultural part, there are risks of greater stress with the increase in evapotranspiration and evaporation.

It is stated that rainfall rates with major irregularities and trends in rainfall reductions in the study area tend to be one more municipality in the semi-arid group.

In the last decade, rainfall contributions were below normal, with occurrences of extreme rainfall in a short period of time not contributing to the agricultural sector, water storage and harming the bare soil of vegetation.

The need to obtain a methodology capable of evaluating the factors that cause water erosion and of estimating annual soil losses resulted in the development of the Universal Soil Loss Equation estimated by [122] and Smith (1958. 1978). This equation is considered a good instrument for predicting soil losses, requiring a relatively small amount of information when compared to more complex models and being well known and studied in Brazil. However, for its use, it is necessary to survey several factors, among them the Rainfall Erosivity (R), which allows the assessment of the erosive potential of precipitation in a given location.

Land use accelerated the erosion processes and. due to this, there is a predominance of morphogenesis to the detriment of pedogenesis, which require readjustment of land use. This readjustment can occur either by modifying the use and occupation of the soil or through mechanical practices of soil conservation.

The main erosive agent in the study municipality is the use, occupation of the soil and conservationist practices, since the classes of agriculture and exposed soil that predominate in the study area are used without many techniques.

The municipality tends to reach aridity values in the desertification range and its tendency is to have a semi-arid climate.

The lack of Public Policies for coexistence with the semiarid region and the lack of effective action by Programs to Combat Desertification in the study area has contributed to environmental degradation. This could be verified through the Simplified Interaction Matrix, which pointed out several socio-environmental problems for the region (accelerated erosion, loss of biodiversity, soil degradation).

Rainfall events such as “Normal Years” were more frequente, followed by lower climate variability and upper climate anomaly events. Among the components of the BH, the water deficit is the one with the highest occurrence, indicating that the local water availability is very low.

Compliance with ethical standards

Disclosure of conflict of interest

All authors had their participation

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