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Water Balance and Erosivity Based on Climate Changes Proposed by IPCC AR4 for The Municipality of Santa Filomena, Piauí State, Brazil

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ABSTRACT

Water balance is an element with the greatest spatiotemporal variability. For this reason, the study of extreme events of maximum annual daily precipitation is related to severe damage to human activities in all regions of the world, due to its potential to cause soil water saturation, runoff, and erosion. This study aims to evaluate the water conditions through the future climate panorama of precipitation and air temperature and the impact of soil erosion in the municipality of Santa Filomena, Piauí State, Brazil. It was calculated the climatological water balance using the method of Thornthwaite and Mather using the series of precipitation from 1962 to 2010, collected by SUDENE and by EMATER-PI. The temperature data were estimated by software -T. Data came for scenarios of precipitation and air temperature monthly average with 10% reduction and 1ºC (optimistic scenario = B2) and 20% and 4 ºC (pessimistic scenario = A2), using methods of IV Assessment Report of the Panel Intergovernmental Climate Change (IPCC AR4). The municipality is classified as having very high erosivity since the erosivity factor (R) found was 33,209.2 MJ mm ha^{-1} year^{-1}. The results obtained in both the optimistic (B2) and the pessimistic (A2) scenarios indicate critical situations of soil conditions, indicating great impacts both for water resources and about the cultivation of rainfed crops. In view of the pessimistic scenario, the condition for storing rainwater for human and animal consumption is critical, requiring future planning for the construction of cisterns and others similar to carry out water storage and minimize impacts. The rainfall indices for scenarios B2 and A2 may lead to more incidences of erosion since heavy rains of large magnitudes and in a short period are expected.

INTRODUCTION

The climate has a great influence on the environment, acting as an interaction factor between biotic and abiotic components. The climate of any region, located in the most diverse latitudes of the globe, does not present the same characteristics each year (SORIANO, 1997).

In recent years, modernization has led to a growth in cities, and with the increase in urbanization, conditions have emerged that have been causing changes in the local climate, mainly due to the construction and activities such as buildings, soil sealing, deforestation, and concentration of machines and people. The absence of urban planning to improve the interaction between human beings and the environment has been excluding natural elements, and inducing the emergence of extreme events, which have consequences in large cities: floods, landslides, the increase in pests, diseases, and deaths (SANTOS, 2007).

Other expected problems are the reductions in rainfall levels that may reach a range of 60% of monthly values, decreasing the water storage in reservoirs, further restricting drinking water for human and animal survival, affecting fauna and flora, and some species may become extinct (MARENGO, 2011).

According to Medeiros et al. (2012) for the municipality of Picuí, Paraíba state, Brazil, rainfall levels will not be sufficient for various types of crops, making it unfeasible for this municipality to develop rainfed agricultural practices, if the pessimistic scenarios are confirmed. It also warns that, given this pessimistic scenario, the condition for storing rainwater for human and animal consumption will be critical, requiring future planning for the construction of cisterns and others similar, which enable the storage of water and minimize the impacts of lack of rain.

The issue of climate change is one of the greatest socio-economic and scientific challenges that humanity will have to face throughout this century. According to Jenkin et al. (2005), the entire planet will suffer from these impacts, but the poorest populations, from the most vulnerable countries, will certainly be the most susceptible to their negative impacts. Santos. (1998) demonstrated that water deficit and the morphological and physiological processes of plants may be affected by climate change.

The main signs of global warming come from temperature measurements from meteorological stations since 1860 across the globe. Data with correction for heat island effects show that the average temperature increase was approximately 0.6 °C during the 20th century, and the largest increases were in two periods: 1910 to 1945 and 1976 to 2000 (IPCC, 2001a). Also, according to IPCC reports (2001a and 2001b), there is a projection of an average increase in the planet's temperature between 1.4 and 5.8ºC between 1990 and 2100. Regarding precipitation, forecasts indicate that there must be a reduction in the tropical and subtropical region and an increase in the average of the regions of higher latitudes. In the Northeast of Brazil, especially in its semi-arid region, which frequently faces the problems of drought and prolonged droughts during the rainy season, these conditions become even more serious (NOBRE et al. 2001).

This work aimed to evaluate the water conditions through the future climate panorama of precipitation and air temperature and the impact of soil erosion in the municipality of Santa Filomena, Piauí State, Brazil.

MATERIAL AND METHODS

The State of Piauí is located in the Brazilian Northeast, covering an area of 251,529.86 km^2, representing 16.2% of the northeastern area and 2.95% of the national area. It is the third-largest state in the Northeast, being surpassed in an area only by Bahia and Maranhão states. It is situated between 2º44'49" and 10º55'05" south latitude and between 40º22'12" and 45º59'42" west longitude (CEPRO, 2003).

The geographic coordinates that delimit the municipal seat of Santa Filomena are latitude 09º05' south and longitude 46º51' west. It is located in a low-latitude zone, which gives it a tropical character. Continentality is another factor, which, along with latitude, ensures the fundamental characteristics of the regional climate, with an average annual temperature of 25.7 °C and monthly fluctuations between 24.3 °C and 28.3 °C, with a maximum annual temperature of 29.2 ºC to 36.0 ºC, monthly minimum temperature of 18.4 ºC to 21 ºC and annual relative humidity of 64.5%. The rainy season starts in October with pre-season and prolonged rains. If until April. The wettest quarter is December, January, and February, and the average annual precipitation is 1,231.2 mm.

For the development of this work, monthly and annual precipitation data series were used, collected by the Superintedência de Desenvolvimento do Nordeste (SUDENE) and provided by the Instituto de Assitência Técnica e Extensão Rural do Piauí – EMATER/PI for the period of 37 years from 1962-2010. Temperature data were estimated by the Estima-T Software, for the period from 1950 to 2010 (CAVALCANTI et al., 2006).

The data were worked for precipitation and average monthly air temperature scenarios with a reduction of 10% and 1°C (optimistic scenario = B2) and 20% and 4 °C (pessimistic scenario = A2), according to the methodology of the IV Evaluation Report of the Intergovernmental Panel of Climate Change (IPCC AR4). Then applying the water balance method of Thornthwaite et al., (1955), using the Normal Water Balance spreadsheet provided by Rolim and Sentelhas (1999). The Available Water Capacity (DAC) defined as the maximum water storage in the soil, was adopted in all scenarios at the reference value of 100 mm, according to Thornthwaite et al, (1955).

To determine the erosivity factor, the equation proposed by Wischmeier (1971) and Wischmeier and Smith (1958, 1978) was used, defined as:

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

where: EI_{30}= the monthly average of the rainfall erosivity index (MJ.mm.ha^{-1}.h^{-1}); r= the monthly average rainfall (mm); and p= the mean 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, enabling proper management and occupation practices (BARBOSA et. al., 2000; MENEZES et. al., 2011). The calculation of this factor is the sum of the monthly erosivity values, according to the equation:

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

RESULTS AND DISCUSSION

The annual distribution of precipitation in the municipality of Santa Filomena is shown in Figure 1. There was a fluctuation of precipitation between 497.8 to 3,290.0 mm, with a historical average of1,436.9 mm, in 37 years of observed data. It is noteworthy that in the periods between the years 1977 to 1983 and 2004 to 2006 no precipitation data were recorded. A trend towards a reduction in annual precipitation was observed, corroborating a study carried out by Lacerda et al. (2010). The high variability in distribution, characteristic of the semi-arid climate, predominant in northeastern Brazil, should be highlighted.

It was observed that the reduction trend would be greater than the decrease in precipitation in the future scenarios B_2 and A_2, as shown in Table 1 and Figure 2. The variability of average rainfall rates and with reductions of 10% and 20%, followed by temperature variability average and their respective variations for increases of 1°C and 4°C. In the A_2 scenario, an increase in temperature was observed, which could lead to greater water deficiencies, causing stress in the cultures, compromising production.

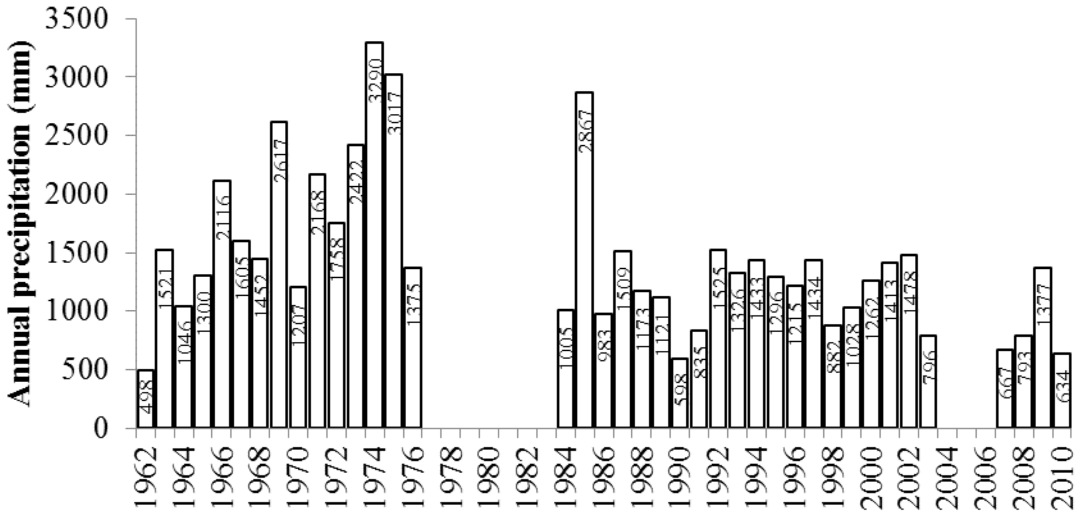

Figure 1 - Average annual distribution of rainfall (mm) from 1962 to 2010 in the municipality of Santa Filomena, Piauí State, Brazil.

Source: Medeiros (2021).

Table 1 - Precipitation (PPT - mm) and average temperature (Temp - °C), scenarios B_2 and A_2.

Months	Average		B_2		A_2	
	PPT	Temp	PPT	Temp	PPT	Temp
	mm	ºC	-10%	+1 ºC	-20%	+4 ºC
Jan	254,6	24,3	229,2	25,3	203,7	28,3
Feb	286,5	24,3	257,9	25,3	229,2	28,3
Mar	249,8	25,3	224,8	26,3	199,8	29,3
Apr	197,4	25,6	177,6	26,6	157,9	29,6
May	48,9	25,6	44,0	26,6	39,1	29,6
Jun	6,2	25,0	5,6	26,0	5,0	29,0
Jul	0,9	25,3	0,8	26,3	0,7	29,3
Aug	0,3	26,5	0,2	27,5	0,2	30,5
Sep	11,4	28,3	10,2	29,3	9,1	32,3
Oct	72,5	28,0	65,2	29,0	58,0	32,0
Nov	133,7	25,5	120,3	26,5	107,0	29,5
Dec	210,5	24,5	189,5	25,5	168,4	28,5
Yaerma	1436,9		1293,2		1149,5	
Average		25,7		26,7		29,7

Source: Medeiros (2021).

In Figure 2, the monthly average distribution of the historical temperature was observed, temperature with 1 ºC over and over 4 ºC and their respective historical precipitations, with reductions of 10% and 20% for the municipality of Santa Filomena. The average annual temperature was 25.7 ºC, with variations between 24.3 ºC and 28.3 ºC.

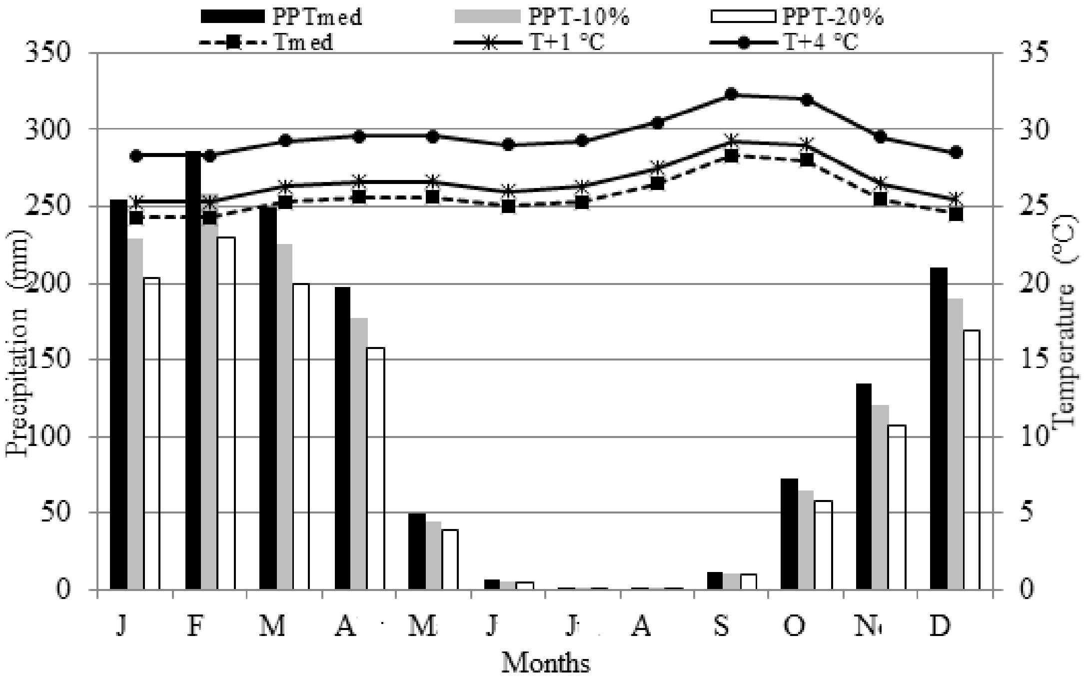

Figure 2 – Behavior of precipitation with an average, reduction of 10% and 20%, and temperature with an average and increase of 1 ºC and 4 ºC, in the municipality of Santa Filomena, Piauí State, Brazil.

Source: Medeiros (2021).

The historical annual average, for 37 years of observations, was 1,436.9 mm, with variability in the annual totals, with the wettest quarter being the months of January, February and March. The month of February stood out from the others due to meteorological factors acting in the southern Cerrado region of Piauí state, which in some years for those months, provided anomalous and high-intensity rains induced by the presence of the large-scale phenomenon La Niña (Table 1; MEDEIROS, 2007).

The calculated values of erosivity and the R factor are shown in Table 2, which shows the variation in the historical monthly averages of precipitation and the evaluations of the EI_{30} index and the R factor. The months from November to April had the highest rainfall indexes, corresponding to 90.51% of the precipitation indexes. The lowest indexes are centered in June to October, which corresponded to 9.49% of the total precipitation that occurred. It can also be seen that February and March have the highest levels of erosivity.

In the evaluations of the erosivity values presented in Table 2, the maximum values were observed in February, followed by the months of March, April, December, and January. The months from June to September are the ones with the lowest erosivity evaluations. The R factor of the study area was 33,209.2 MJ mm ha^{-1} year^{-1}, with a very high concentration of erosive, according to Wischmeier (1971) and Wischmeier and Smith (1958, 1978).

Table 2 - Average monthly and annual precipitation, and Erosivity Index (EI$_{30}$) and R Factor.

Months	Montlhy averages	EI$_{30}$	R
JAN	254,6	1680,7	
FEB	286,5	2054,1	
MAR	249,8	1626,6	
APR	197,4	1090,2	
MAY	48,9	101,8	
JUN	6,2	3,1	33.209,2
JUL	0,9	0,1	
AUG	0,3	0,0	
SEP	11,4	8,5	
OCT	72,5	198,4	
NOV	133,7	562,2	
DEC	210,5	1216,5	
ANNUAL	1472,7	33209,2	

Source: Medeiros (2021).

The erosivity indices shown in Figure 3 follow the precipitation distribution, which agrees with the principle proposed by Lemos and Bahia (1992).

Regarding precipitation, forecasts indicate that there may be a reduction in the tropical and subtropical regions 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 Ñino/La Ñina) (MEDEIROS, 2007), historical averages, even in times of the rainy season, fluctuated within and below normality. The spatial and temporal variabilities were influenced by the meteorological systems operating at the time; their tendency is that rainfall indices below climatology persist in future scenarios B_2 and A_2. Santana et al. (2007) worked in Minas Gerais state, Brazil, in the semiarid region, demonstrating that the variability of the rainy season depended solely and exclusively on the factors that caused rainfall.

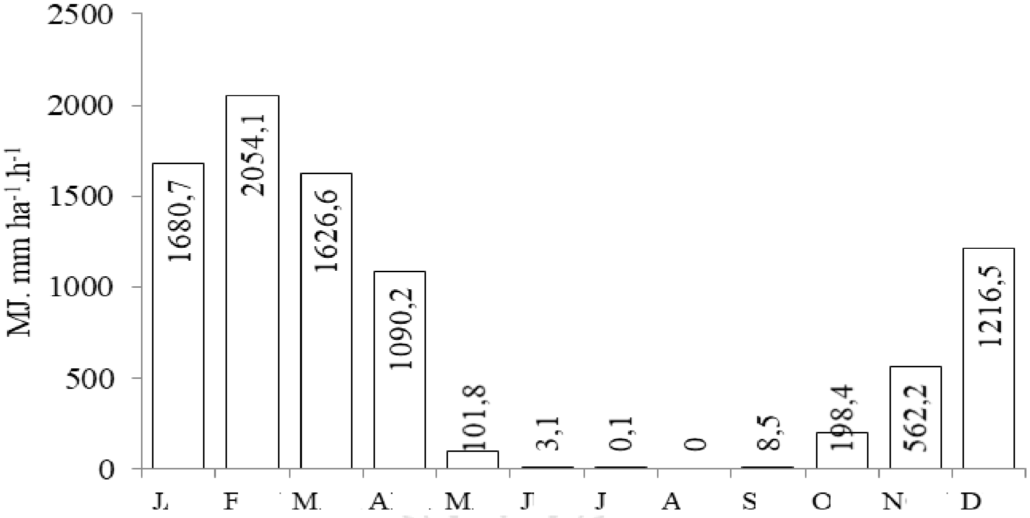

Figure 3–Monthly averages erosivity in the period from 1962 to 2010 in the municipality of Santa Filomena, Piauí State, Brazil.

Source: Medeiros (2021).

Carvalho et al. (2004) used the water balance as a qualitative classification proposal for rainfall and temperature variability, with the water balance data determining the most critical periods of water deficit in the soil, demonstrating to public decision-makers the possibilities of trends in future agricultural scenarios where strategies must be taken to ensure greater and better productions (Santos, 2010).

The climatological water balance (normal) and the water balances with reductions of 10% and 20% mean monthly are shown in Figures 4, 5, and 6. It was observed that in Figure 4 the excess for normal condition occurred from December to April with fluctuation between 11.5 and 189.8 mm and the deficiency fluctuated between May and October, with an oscillation from 20.7 to 155.1 mm. In Figure 5, it was observed the water balance for scenario B_2, where the surpluses occurred between January and April with fluctuations from 42.9 to 149.8 mm, and the deficiencies varied between May and November with fluctuations from 17.0 to 182.1 mm. Figure 6 represents the water balance for scenario A_2. It was noted that there were no surpluses and water deficits evolved with variations between March to December.

Leaf's et al. (2006) presented the average and extreme values of air temperature and precipitation, which established a possible characterization of the beginning and end of the rainy season in this region, as well as an evaluation of the time series of climatic elements to support the issues on climate change in the region.

Medeiros et al .(2012) found the factor (R) for the municipality of Areia, Paraíba state, Brazil, of 31,528.8 MJ mm. $ha^{-1}h^{-1}$year, and established that the highest erosivity indices were from March to August, which coincide with the rainy season and the field capacity at maximum values. For September, they found the first fortnight of February, the lowest erosivity indexes occurred, corresponding to the dry period and the beginning of the pre-season rains.

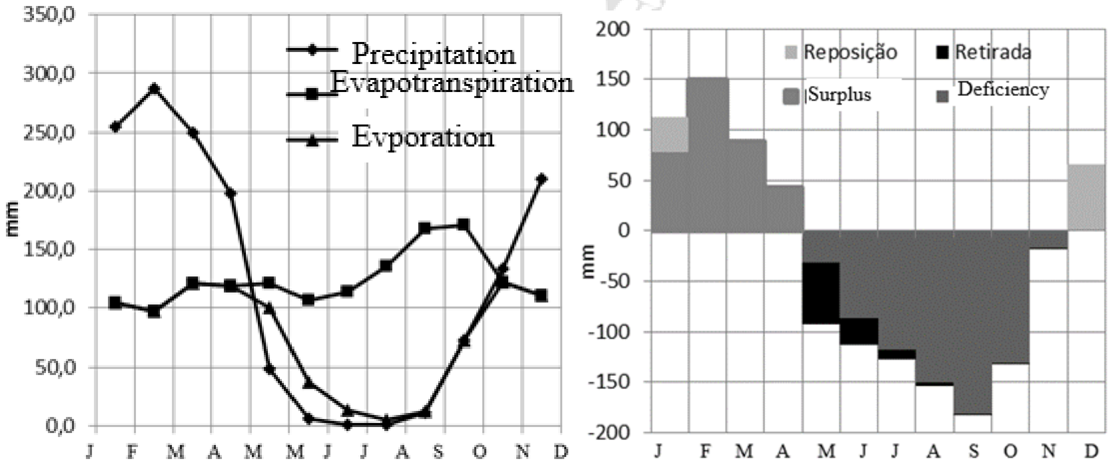

Figure 4 - Climatological water balance with the climatological mean of air temperature and precipitation in the municipality of Santa Filomena, Piauí State, Brazil.

Source: Medeiros (2021).

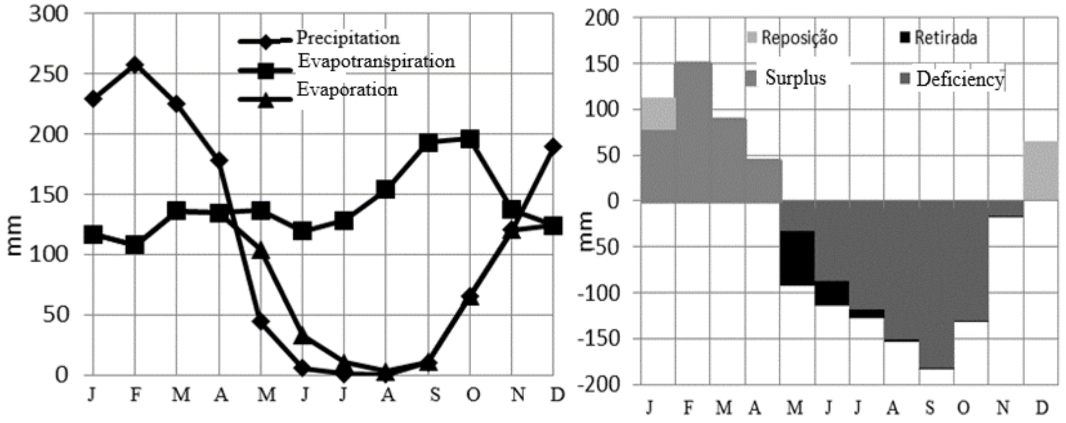

Figure 5 - Simulated water balance with IPCC-AR4 B2 scenario in the municipality of Santa Filomena, Piauí State, Brazil.

Source: Medeiros (2021).

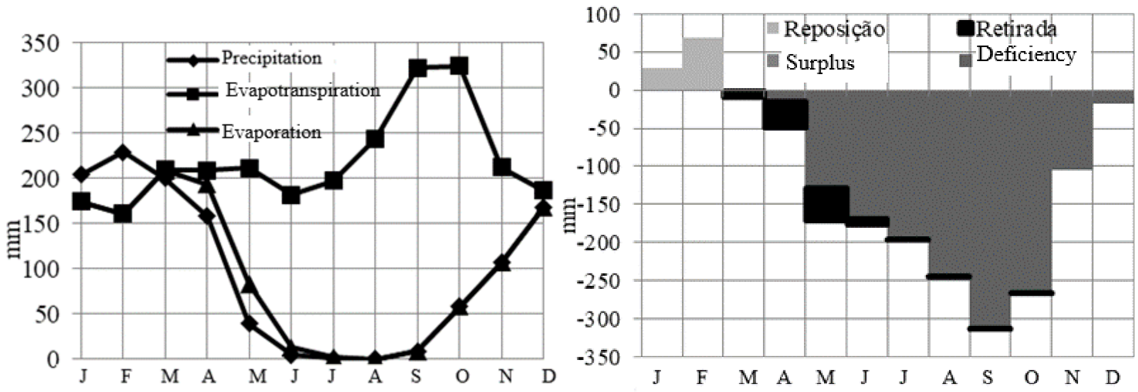

Figure 6 - Water Balance simulated with the IPCC-AR4 A_2 scenario in the municipality of Santa Filomena, Piauí State, Brazil.

Source: Medeiros (2021).

The annual value of potential evapotranspiration (1,489.6 mm) was equal to that of precipitation (1,436.9 mm); the value of actual evaporation was 36.33% of annual precipitation. According to the statements for scenarios B_2 and A_2, this value is subjected to significant changes. If these changes are confirmed, rainfed agriculture and water supply will be compromised.

There were fluctuations in the potential evapotranspiration, real evaporation, water deficit, and water surplus for the studied scenarios (Table 3).

The meteorological elements studied and discussed here show that for scenarios B_2 and A_2, there will be sudden changes and that the inhabitants will have to change their tactics in the future about planting, water storage, and survival conditions.

Table 3 - Water balance for normal, B_2, and A_2 scenarios.

Months	Normal				B_2				A_2			
	ETP	ETR	DEF	EXC	ETP	ETR	DEF	EXC	ETP	ETR	DEF	EXC
Jan	104,7	104,7	0,0	150,0	116,9	116,9	0,0	77,5	174,4	174,4	0,0	0,0
Feb	96,7	96,7	0,0	189,8	108,0	108,0	0,0	149,8	161,1	161,1	0,0	0,0
Mar	121,1	121,1	0,0	128,7	136,3	136,3	0,0	88,5	209,2	208,5	0,7	0,0
Apr	119,4	119,4	0,0	78,0	134,7	134,7	0,0	42,9	208,5	193,2	15,4	0,0
May	120,9	100,2	20,7	0,0	136,4	104,3	32,1	0,0	211,1	83,0	128,1	0,0
Jun	106,2	37,0	69,2	0,0	119,3	32,6	86,7	0,0	181,5	12,9	168,5	0,0
Jul	114,1	13,0	101,0	0,0	128,4	10,0	118,4	0,0	197,0	2,1	194,9	0,0
Aug	135,4	4,6	130,8	0,0	153,7	3,0	150,7	0,0	244,0	0,4	243,6	0,0
Sep	167,7	12,6	155,1	0,0	193,0	10,9	182,1	0,0	321,9	9,1	312,8	0,0
Oct	170,6	72,6	98,0	0,0	195,9	65,3	130,6	0,0	324,1	58,0	266,1	0,0
Nov	121,8	121,8	0,0	0,0	137,3	120,3	17,0	0,0	211,9	107,0	105,0	0,0
Dec	111,0	111,0	0,0	11,5	124,2	124,2	0,0	0,0	186,3	168,4	17,9	0,0
Total	1489,6	914,8	574,8	557,9	1684,1	966,6	717,5	358,8	2631,1	174,4	0,0	0,0

ETP – Potential evapotranspiration; ETR – Actual Evaporation; DEF – Water Deficiency and EXC – Water Surplus.

Source: Medeiros (2021).

CONCLUSION

The municipality is classified as having very high erosivity since the erosivity factor (R) found was 33,209.2 MJ mm ha^{-1} $year^{-1}$.

The results obtained in both the optimistic (B_2) and the pessimistic (A_2) scenarios indicate critical situations of soil conditions, indicating great impacts both for water resources and about the cultivation of rainfed crops.

Because of the pessimistic scenario, the condition for storing rainwater for human and animal consumption is critical, requiring future planning for the construction of cisterns and others similar to carry out water storage and minimize impacts.

The rainfall indices for scenarios B2 and A2 may lead to more incidences of erosion since heavy rains of large magnitudes and in a short period are expected.

Rainfall rates for scenario A2 will not be sufficient for various types of crops, making it unfeasible for this municipality to develop rainfed agricultural practices.

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