Climate change in Tacaimbó-PE, Brazil

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Abstract

The objective of this study was to evaluate the climatic changes in the municipality of Tacaimbó-PE and the water conditions through the future climatic panorama of precipitation and air temperature in order to show the effects of global warming on the climatic water balance. The data were analyzed for rainfall scenarios and average monthly air temperature 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 Fourth Assessment Report of the Intergovernmental Panel of Climate Change (IPCC AR4). It was applied the Thornthwaite and Mather (1948, 1955) method for the water balance. The rainfall indexes will not be enough for several types of crops, so it is not feasible for this municipality to develop dryland farming practices, in case these scenarios come up, mainly analyzing the slope of the pessimistic scenario. In the face of this pessimistic scenario, it is critical the condition for storing rainwater for human and animal consumption, being necessary a future planning for tank constructions and similar constructions is required for water storage and impact minimization.

Keywords: climatic and meteorological factors, deficiencies and hydrographic overbalance.

1. Introduction

The general circulation of the atmosphere contributes to the types of climates that exist in the planet Earth. Therefore, the climatic elements are responsible for the dynamics of the atmosphere, in mutual and successive interaction with the terrestrial surface.

Important variables that can affect agricultural crops are those obtained through the Climatological Water Balance (CWB), which is of fundamental importance in several studies of a given region, that is, in the determination of favorable locations for certain types of crops, climatic classification, etc. Several authors such as Alfonsi et al. (1990), Pereira (2002) and Varejão-Silva (2005) define water balance as being the soil water accounting, that is, the computation of all water gains and losses, together with their storage, in the soil or basin. In the water balance, there are components such as: precipitation and/or irrigation, which are the major suppliers of water to the soil, the superficial defluvium, the amount of water stored in this soil, the deep drainage, and finally (always considering this vegetated soil), the simultaneous evaporation and transpiration of plants which is denominated evapotranspiration, where the equation composed by these variables is considered so that all of

them are zero, contributing to the reasoning of the water balance.

Other expected problems are the reductions in rainfall levels, which could reach a range of 60% of the monthly values, with this the water storage reservoirs will become obsolete, restricting even more potable drinking water for human and animal survival, as well as changes to the fauna and flora, and some species may become extinct according to Marengo et al. (2011).

Menezes et al. (2015) analyzed the behavior of water and soil conditions for the city of Bom Jesus - PI, based on future climatic scenarios. Climatological water balance was estimated according to the Thornthwaite and Mather method (1948, 1955) and were figured with scenarios according to the methodology of the IV IPCC Report, which provides a pessimistic scenario (A2), a 20% reduction in rainfall and an increase of 4°C in the average temperature of the air. In an optimistic scenario (B2) the IPCC predicts a reduction of 10% in precipitation and an increase of 1°C in air temperature. The annual value of potential evapotranspiration was 1,573.9 mm for the normal scenario, 1,789.1 mm for scenario B2 and 2843.7 mm for scenario A2, which corresponds to 62.6%; 55.04% and 34.63% of the annual precipitation (984.8 mm) respectively. The evaporation values were 928.2 mm;

886.2mm and 787.8mm for scenario B2 and A2 respectively. These values could have significant impacts on rainfed agricultural activities and on water supply if such changes in the region's climate are confirmed. There will be no water surpluses for scenarios B2 and A2. The water deficit registered a significant increase, which could cause water stress in most crops. Extreme precipitation events in scenarios B2 and A2 may increase intensity and may aggravate soil erosion processes in the region. It was verified that the region falls into the category of extremely high erosivity, since the erosivity index (R) found was 29,504.7 MJ mm ha⁻¹ year⁻¹.

Medeiros et al. (2015) evaluated the water balance and rainfall erosivity due to the climate change scenario for the municipality of Cabaceiras - PB. They used monthly and annual precipitation data for the period 1926-2010. The temperature series for the period from 1950 to 2010 was estimated using the aod of Software Estima_T, following the methodology proposed by the IPCC AR4. The Universal Soil Loss Equation was used to determine the rainfall (R) Erosivity index. The analysis for the optimistic scenario (B2) and pessimistic scenario (A2) indicated critical situations of the soil conditions that will cause significant losses for the water resources and rainfed crops.

Medeiros et al. (2014) showed that rainfall erosivity indices in the area of the Uruçuí Preto-PI river basin are of very high concentration. They used monthly precipitation data from the period from 1960 to 1990. The total erosive index of 28,429.1 MJ mm ha⁻¹ h⁻¹ year⁻¹ was determined using the Wischmeier and Smith equation. It was observed that the highest rates of erosivity occurred in the months of November to April coinciding with rainy season. However, the field capacity presents maximum values in the months of May to October (drought period) coinciding with the lowest values of erosivity.

A study by Medeiros et al. (2012) for the municipality of Picuí, PB indicates that the rainfall indices will not be enough for several types of crops, which makes it impossible to grow rainfed crops if the pessimistic scenarios are confirmed. The author also warns that in the face of the pessimistic scenario, the condition for the storage of rainwater for human and animal consumption will suffer significant impacts, therefore, it is necessary the planning to coexist with the drought through the construction of tanks and other similar constructions that allow the storage of water and minimization of the impacts from the lack of rainfall.

Medeiros et al. (2015) used average monthly climatological precipitation data provided by EASA from the period 1912 to 2014. The temperature data were estimated by the Estima_T Software. With the data obtained were elaborated optimistic scenarios and pessimistic scenarios and it was applied the water

balance method with the reference value of 100 mm for the six homogeneous regions of the State of Paraíba and the erosivity was calculated. The results demonstrated that evapotranspiration showed increases in all regions and in both scenarios; The evaporative indices remained reduced in the two scenarios; Water deficiencies and surpluses have suffered ups and downs for all scenarios; it was verified reductions in erosivity for all the studied regions; The R factor was 43,776.3 MJ mm.ha⁻¹.ano⁻¹, in the Coastal area; 25,135.1 MJ mm.ha⁻¹.no⁻¹, in the "Agreste"(wild) ; 30,675.9 MJ mm.ha⁻¹.no⁻¹, in the Swamp region; 17,361.8 MJ mm.ha⁻¹.an⁻¹, Cariri /Curimataú; 24.140,5 MJ mm.ha⁻¹.ano⁻¹, in the backwoods 27,326.9 MJ mm.ha⁻¹.year⁻¹.

The monthly BHC for the area of the Uruçuí Preto river basin (BHRUP) was carried out according to the method of Thornthwaite and Mather (1948, 1955), aiming at agricultural and hydrological planning of possible climatic changes. The estimated average air temperature was estimated using the "Estima-T" software, referring to the period from 1960 to 1990 and monthly rainfall. The field storage capacity (FSC) of 100 mm was used. The BHC resulted in eight months (April to May) of water deficiency with a total accumulated of 643.4 mm, occurring water surplus in the months of February and March, evapotranspiring 90% of the rainfall indices. No climate change trends have been observed on rainfall indices and these indices can occur in short time intervals and with high intensity. There should be a good sustainable planning for the agricultural and hydrological sector since the irregularities of the rains are extreme and also there should be a way to store water from the pre-season to the end of the rainy season according to Medeiros (2014).

Costa et al. (2015) evaluated the variation of evaporation in the class "A" tank in the municipality of Teresina-PI for three and a half decades and compared the changes in the urbanization which occurred in that period, finding changes in the evaporative indices in view of the occupation of man and their respective modifications in space. The wind block due to horizontal growth has contributed to the reduction of evaporation (EVR), the opposite occurs when it rains, there is no surface runoff and at the end of the precipitation the evaporative indices occur in larger proportions due to the heat exchange. The series of daily evaporation data used in this study was separated between periods, from 1986-1995, 1996-2005, 2006-2011 and compared with the complete series of 1976-2011, culminating with an analysis comparing the 35 years of data with the year of 2011. It was verified the oscillations of smaller and higher values occurred, especially in the 1976-1985 and 1986-1995 decades, which presented the smallest variations. The decade of 2006-2011 in the month of October presented the greatest 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 1996 decade, due to the urban verticalization, alteration of the vegetal area, soil compaction with the paving, grounding of ponds and eutrophication of the water mirrors.

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

The objective of this study was to evaluate the climatic changes in the municipality of Tacaimbó-PE and the water conditions through the future climate scenario of precipitation and air temperature in order to show the effects of global warming on the climatic water balance.

2. Materials and methods

Tacaimbó is located in the geographical coordinates of latitude 08°20' south and longitude 36°17' west, with an average altitude of 576 meters. Its population estimated in 2010 was of 12,095 inhabitants, with demographic density of 57.60 hab / km². It has a territorial area of 210.94 km², Figure 1. It has as intermunicipal limits by the north and west with the city of Belo Jardim; In the east sector it is limited with São Caetano and to the south it is limited with Cachoeirinha, distance of the capital 170 Km in a straight line.

Figure 1 - Location of the municipality of Tacaimbó within the state. Source: adapted by the author.

Tacaimbó is inserted in the mesoregion of the “agreste” and in the geoenvironmental unit of the Plateau of Borborema, formed by massive and high hills, with altitudes varying between 650 and 1000 meters. In relation to the fertility of the soils it is quite varied, with a certain predominance from average to high. The area of the unit is cut by perennial rivers, but of small flow and the groundwater potential is low.

The vegetation is formed by subsurface, sub-deciduous and deciduous forests, typical of wilderness areas.

In the soft undulating Surfaces, Planosols occur, medium to deep, heavily drained, acid to moderately acid and medium natural fertility, and also the Podzolics, which are of a deep clayey texture, and with medium to high natural fertility. In the elevations occur Litolics, shallow soils, clayey texture and average natural fertility. In the valleys of rivers and streams, Planosols occur, moderately deep, imperfectly drained, medium/clayey texture, moderately acidic, high natural fertility and salt problems. There are also Rock outcrops.

According Alvares et al. (2013), Tacaimbó's climate according to the Köppen-Geiger classification is type A (rainy tropical, with dry summer, rainy season moving into autumn). The rainy season begins in February with pre-season rains (rainfall occurring before the rainy season) with its end occurring at the end of August and may extend until the first half of September. The rainy trimester focuses on the months of May, June and July and its driest months occur between October, November and December. The factors that cause rain in the city are the contributions of the Intertropical Convergence Zone (ITCZ), formation of high level cyclonic vortices (FHLCV), influence of the contribution of the northeast trade winds in the transport of steam and humidity, formations of instabilities lines, the orography and its local contributions forming clouds and causing moderate to strong rains.

It was used monthly and annual data series of precipitation and air temperature provided by the Pernambuco State Agency for Water and Climate (PAWC) for the period of 1960-2015.

The data were analyzed for rainfall scenarios and average monthly air temperature, 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 Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4). It was applied the Thornthwaite and Mather (1948, 1955) water balance method, developed by Medeiros (2014) using spreadsheets following the formulations of Thornthwaite and Mather (1948, 1955). The Available Water Capacity (AWC) defined as the maximum water storage in the soil was adopted in all scenarios using the reference value of 100 mm, according to Thornthwaite and Mather (1955).

3. Results and discussion

The global climate has been changing over the years, which leads to thinking about the actions of men, when they change the environment, and through new technologies that seek to meet the pressures of increasingly demanding consumption patterns. In Tacaimbó, the result of these practices can be observed

in the behavior of the climate, more precisely in the air temperature, relative humidity and precipitation, because they manifest themselves more directly in the daily life of the population.

Figure 2 shows the temperature variability: maximum, minimum, average and thermal amplitude of the studied area.

The average annual temperature is 22.3°C and its monthly oscillations occur between 19.9°C in July and 24°C in January.

Figure 2 - Temperature fluctuations: maximum, minimum, average and thermal amplitude for the city of Tacaimbó. Source: adapted by the author.

The variability of historical precipitation and relative air humidity for the city of Tacaimbó - PE, for the period 1962-2015 is represented in Figure 3. The monthly irregularity in rainfall indices is due to the meteorological factors that inhibit and/or activate rainfall systems in the studied area.

Figure 3 - Behavior of historical pluvial precipitation and relative air humidity for the city of Tacaimbó - PE, referring to the period 1962-2015. Source: adapted by the author.

The municipality of Tacaimbó records rainfall of 616.4 mm annually-1. The months of March to July show the highest incidence of precipitation, contributing 69% of the annual index. Between August and February the rainfall indexes are low and its contribution is 31% of the annual value.

Hydric balance

The water balance can be studied at various scales. On a global scale, it deals with the circulation of water between the earth and the atmosphere. Libardi (1995) illustrated the distribution of water with numerical values, where 96.0% of the total water on the continents, oceans and atmosphere are represented by the oceans. The water of the continents represents 4.0% of the total and the atmosphere 0.001%.

Climatological water balance, described by Thornthwaite and Marther (1955), is one of several ways of monitoring soil water storage. By using only monthly average values of temperature and precipitation, it can not respond to emergencies where it is required to know the different monthly probabilities of occurrences of excess and water deficiency. However, starting from an available water capacity (AWC) appropriate to the type of crop plant, it produces useful results for the climatological characterization of the region and it informs about the distribution of deficiencies and excesses of rainfall, the storage of water in the soil, both on a daily, monthly and regional scale.

The climatic water balance allows quantifying these terms and is an excellent tool to study also the variability of implantation and monitoring of irrigation or drainage systems in a region.

The Figure 4 shows the behavior of evapotranspiration and evaporation by calculating the climatological water balance for the city of Tacaimbó - PE, for the period of 1962-2015. It should be noted that evaporation is greater than evapotranspiration between the months of January, February, March, May, August, September, October, November and December, and in April and June these values are equal.

The evapotranspiration oscillates between 64.2 mm in the month of July to 110.6 mm in December, the annual evapotranspiration is 1.075.5 mm almost twice the value of the annual precipitation. The evaporation flows between 17.6 mm in the month of October to 99 mm in the month of March and its annual rate is 616.8 mm, it evaporates 0.4 mm more from the annual precipitation rate.

Figure 4 - Behavior of evapotranspiration and evaporation by calculating the climatological water balance for the city of Tacaimbó - PE, for the period of 1962-2015. Source: adapted by the author.

The average municipal temperatures oscillate between 19.9°C in July and 24°C in January, with an average annual value of 22.3°C. When no surplus is detected, this means that the precipitation is equal to or approximate to the actual annual evaporation. In the municipal area it was detected surpluses in the months of March and April.

In contrast to the moderate water excesses of the rainy season, the dry period, besides being relatively long, usually has large water deficits, extending from August to March and May, with the exception of the months of April, June and July that show zero value. The annual deficiency is 458.6 mm.

Table 1 - Climatological water balance with the field capacity of 100 mm for the municipality of Tacaimbó-PE.

Meses	¹ T	² P	³ ETP	⁴ EVR	⁵ DEF	⁶ EXC
Jan	24,0	36,5	110,5	37,2	73,3	0,0
Fev	23,8	54,4	99,9	54,6	45,4	0,0
Mar	23,7	99,0	107,0	99,0	8,0	0,0
Abr	22,8	108,2	92,0	92,0	0,0	0,0
Mai	21,7	70,7	82,3	72,6	9,8	0,0
Jun	20,5	68,9	67,0	67,0	0,0	0,0
Jul	19,9	76,9	64,2	64,2	0,0	0,0
Ago	20,1	27,1	66,4	36,6	29,8	0,0
Set	21,5	21,0	78,4	29,7	48,7	0,0
Out	22,7	11,3	95,3	17,6	77,7	0,0
Nov	23,4	16,2	101,8	19,0	82,8	0,0
Dez	23,8	26,3	110,6	27,5	83,2	0,0
Anual	22,3	616,4	1075,5	616,8	458,6	0,0

¹T = Average temperature (° C); ²P = Historical rainfall (mm); ³ETP = Evapotranspiration (mm); ⁴EVR = Evaporation (mm); ⁵DEF = Water deficit (mm); ⁶EXC = Water surplus (mm).

The indices of humidity, dryness and water according to the calculation of the climatological water balance are 42.65%, 0.43% and -0.26%, respectively. Figure 5 shows the climatic water balance variability referring to water restitution, soil water withdrawal, surplus and water deficit for the 100 mm CAD.

Water restitution occurs in the months of April, June and July. No water surplus occurred. Water deficiencies did not occur in the months of April, June and July. Water withdrawal in the soil occurred between May, August, September, October, November and December.

The Table 2 shows the climatic water balance with field capacity of 100 mm, with temperature increase of 1°C and rainfall reduction of 10% for the municipality of Tacaimbó - PE.

Comparing the climatological water balance of Table 1 with Table 2, there was an increase in

temperature, evapotranspiration and water deficit and reduction of precipitation and evaporation in the water surpluses remained at the same level.

Figure 5 - Climatological water balance (CAD 100 mm) for the city of Tacaimbó - PE, referring to the period of 1962-2015. Source: adapted by the author.

Table 2 - Climatological water balance with 100 mm field capacity, with +1°C temperature increase and 10% rainfall reduction, for the municipality of Tacaimbó - PE.

Meses	¹ T	² P	³ ETP	⁴ EVR	⁵ DEF	⁶ EXC
Jan	25,0	32,9	121,3	32,9	88,5	0,0
Fev	24,8	48,9	109,7	48,9	60,8	0,0
Mar	24,7	89,1	117,4	89,1	28,3	0,0
Abr	23,8	97,4	100,5	97,4	3,1	0,0
Mai	22,7	63,7	89,4	63,7	25,8	0,0
Jun	21,5	62,0	72,3	62,0	10,3	0,0
Jul	20,9	69,2	69,2	69,2	0,0	0,0
Ago	21,1	24,4	71,6	24,4	47,2	0,0
Set	22,5	18,9	85,1	18,9	66,1	0,0
Out	23,7	10,1	104,1	10,1	93,9	0,0
Nov	24,4	14,6	111,5	14,6	96,9	0,0
Dez	24,8	23,7	121,4	23,7	97,7	0,0
anual	23,3	554,8	1173,4	554,8	618,6	0,0

¹T = Average temperature (° C); ²P = Historical rainfall (mm); ³ETP = Evapotranspiration (mm); ⁴EVR = Evaporation (mm); ⁵DEF = Water deficit (mm); ⁶EXC = Water surplus (mm).

The Figure 6 shows the climatic water balance variability related to water replenishment, soil water withdrawal, surplus and water deficit with a 1°C temperature increase and a 10% rainfall reduction for the municipality of Tacaimbó - PE, referring to the period of 1962-2015.

With an increase of 1 ° C and a reduction of rainfall by 10%, water deficits increases and causes disasters in the levels of dams, agribusiness, agriculture and livestock among many other areas.

Figure 6 - Climatic water balance (CWB 100 mm) with temperature increase of +1°C and rainfall reduction in 10%, for the municipality of Tacaimbó - PE, for the period of 1962-2015. Source: adapted by the author.

The Table 3 shows the climatic water balance demonstration with the field capacity of 100 mm, with temperature increase of 4°C and rainfall reduction of 20%, for the municipality of Tacaimbó - PE.

Table 3. Climatological water balance with 100 mm field capacity, with temperature increase of +4°C and rainfall reduction of 20%, for the municipality of Tacaimbó - PE.

Meses	¹ T	² P	³ ETP	⁴ EVR	⁵ DEF	⁶ EXC
Jan	28,0	29,2	172,2	29,2	143,0	0,0
Fev	27,8	43,5	155,1	43,5	111,6	0,0
Mar	27,7	79,2	165,5	79,2	86,3	0,0
Abr	26,8	86,5	139,4	86,5	52,8	0,0
Mai	25,7	56,6	121,6	56,6	65,0	0,0
Jun	24,5	55,1	95,9	55,1	40,8	0,0
Jul	23,9	61,5	90,8	61,5	29,3	0,0
Ago	24,1	21,6	94,3	21,6	72,6	0,0
Set	25,5	16,8	115,1	16,8	98,3	0,0
Out	26,7	9,0	144,1	9,0	135,1	0,0
Nov	27,4	13,0	156,4	13,0	143,4	0,0
Dez	27,8	21,0	171,4	21,0	150,3	0,0
anual	26,3	493,1	1621,8	493,1	1128,7	0,0

¹T = Average temperature (° C); ²P = Historical rainfall (mm); ³ETP = Evapotranspiration (mm); ⁴EVR = Evaporation (mm); ⁵DEF = Water deficit (mm); ⁶EXC = Water surplus (mm).

Comparing the climatological water balance of Table 2 with Table 3, there was an increase in temperature, evapotranspiration, evaporation and water deficit and reduction of precipitation, the water surplus remained at the same level.

The Figure 7 shows the climatic water balance variability related to water replenishment, soil water withdrawal, surplus and water deficit with temperature increase of 4°C and a 20% reduction in rainfall for the municipality of Tacaimbó – PE, referring to the period of 1962-2015.

With the increase of 4°C and reduction of rainfall by 20%, water deficiencies increase and cause greater disasters in the levels of dams, agribusiness, agriculture and livestock among many other areas. The population should use rainwater storage every day, and the agricultural sector should plant seeds in advance always resistant to low rainfall.

Figure 7 - Climatic water balance (CWB 100 mm) with temperature increase of +4°C and rainfall reduction in 20%, for the municipality of Tacaimbó – PE, referring to the period of 1962 -2015. Source: adapted by the author.

The Figure 8 shows the behavior of average precipitation, 10% and 20% precipitation reduction, and the average temperature and temperature increase of 1°C and 4°C for the municipality of Tacaimbó – PE.

Figure 8 - Precipitation behavior with average, 10% and 20% reduction, and temperature with average and increment of 1°C and 4°C. Source: Medeiros (2017).

4. Conclusions

The results obtained in both optimistic (B2) and pessimistic (A2) scenarios indicate critical situations of soil conditions that will cause great impacts both to water resources and as regards to the practice of rainfed crops.

The rainfall indexes will not be enough for several types of crops, so it is not feasible for this city to develop dryland farming practices, in case these scenarios arise, specially analyzing the pessimistic scenario.

Before this pessimistic scenario, the condition for the storage of rainwater for human and animal consumption is critical, and future planning for tank constructions and other similar ones is necessary to carry out water storage and minimize impacts.

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