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Water balance of the Córrego Seco microbasin in Caratinga, Minas Gerais, southeastern Brazil

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Abstract: In order to assess the water balance of the Córrego Seco watershed in the municipality of Caratinga, MG, hydrological calculations were carried out using the Thornthwaite - Mather method. This research is quantitative in nature and is specifically a case study. The result of the water balance showed that the months with the highest evapotranspiration, i.e. over 100 mm, were January, August, September, October and December. The greatest water deficits occurred between March and November, characterizing the dry season, but the greatest rainfall occurred between December and February, characterizing a wetter, rainy season, demonstrating that the area studied has two very distinct and defined seasons.

Key words: watershed basin; water balance; Caratinga

1 Introduction

Water is one of the most important and essential natural resources for life on the planet, making it indispensable for the development of all species. Population growth, unplanned urbanization and the advancement of the industrial sector have put a strain on water resources, and in some regions availability is becoming scarcer every day. Several cities in Brazil, especially in the eastern state of Minas Gerais, have already suffered water supply problems due to a lack of planning and protection of water resources.

In 2007, the city of Caratinga, located in the east of Minas Gerais, was very close to having its water supply collapse, as the main spring that supplies raw water to the concessionaire reached a level below its operating capacity of the last thirty years.

According to (UNESCO, 1982), in order to correctly assess the availability of a region's water resources and their spatial and temporal variability, water balances at the basin and regional level are valuable tools from both a theoretical and practical point of view. In this way, the water balance is an instrument that makes it possible to assess the storage of surface and underground water, as well as to carry out a study of the hydrological regime, thus improving the exploitation and protection of water resources in an appropriate manner without overloading the system.

Calculating the water balance is fundamental to knowing potential evapotranspiration, actual evapotranspiration, changes in storage, deficiency, excess, runoff and accumulated negative evapotranspiration, so that we know what the reality is in terms of water storage in the soil. By knowing the water balance, we will have a guide for good agricultural planning and water supply without compromising the water resource.

The Córrego Seco watershed has rural characteristics, where farming activities are intense, causing serious problems for water resources, hence the importance of the water balance to propose better management of activities.

The watershed is a fundamental geomorphological unit of the earth's surface, considered to be the main physiographic unit of the terrain because its characteristics govern all surface water flow within it. It is therefore an ideal area for integrated planning of natural resource management in the environment it defines. The concept of a basin naturally requires the existence of water dividers, headwaters or springs, main watercourses, tributaries and sub-tributaries, as well as a hierarchy of drainage channels and a distribution of predominant soils (Tucci, 2004).

The river basin has been adopted as the basic unit for environmental studies and planning work, as its biogeographical characteristics present relatively cohesive ecological and hydrological systems, which interact with each other, forming functional units (Pires & Santos, 1995).

Considering the available geological mapping data, which is the basis for information on relevant hydrogeological parameters, this methodology assumes that during periods of water recession, associated with the seasonality of rainfall, the hydrogeological systems or units are largely responsible for maintaining the base discharges of a region's watercourses, Gonçalves et al (2005).

Watersheds are of fundamental importance for studies, analyses and evaluations of the hydrological cycle, since they are considered to be a territorial unit. For these procedures, mathematical models are needed to carry out the calculations. The aim of these models is to understand and evaluate the hydrological system.

The water balance can be understood as the process of the hydrological cycle. The process can occur in the surface-atmosphere direction, in the form of vapor, which is considered the main element responsible for the continuous circulation of water around the globe; or in the atmosphere-surface direction, with water returning to the surface in liquid and solid phases, through precipitation (Tucci, 1993).

Through the results of water balance calculations, it is possible to determine a more concrete policy for water resource management. There are several methods for calculating water balance, but with different specificities. Among the various methods for calculating the estimated water balance, the Thorntwaite-Mather methods (1955) were used.

The Caratinga meteorological station is located in the Nossa Senhora das Graças neighborhood at the geographic coordinates: 19º 42' 00" South latitude and 42º 04' 00" West longitude, as per Table 1.

Table 1. Inventory of climatological, fluviometric and rainfall stations

Código	Estação	Município	Altitude (m)	Latitude	Longitude
OMM83592	Caratinga	Caratinga	609.65	19º 42' 00"	42º 04' 00"

Source: BDMEP – INMET

2 Methodology

The Córrego Seco-Caratinga hydrographic microbasin, MG, is located east of the state of Minas Gerais and west of the municipality of Caratinga, whose geographic coordinates are 19º 45' 14.04" S latitude and 42º 07' 32.57" W longitude, as shown in Figure 1.

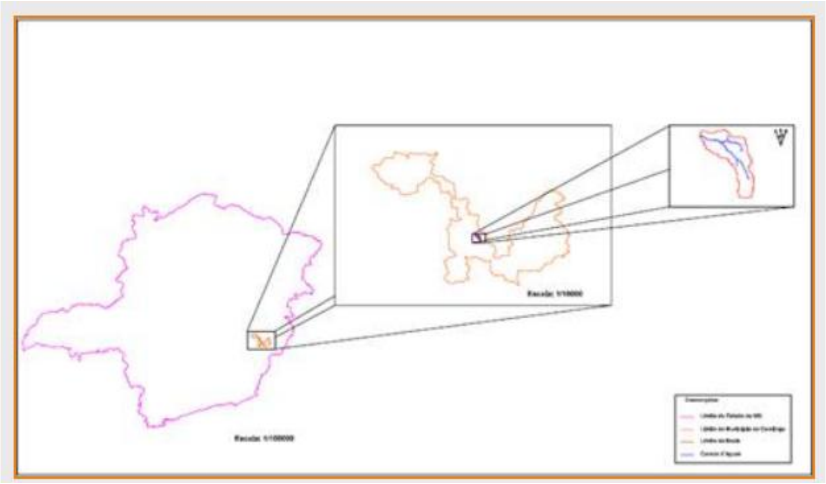


Figure 1. Location of the Córrego Seco hydrographic microbasin – Caratinga, MG

Source: Modified from Miranda, 2005. Map SE 23 – Z – D – VI. Scale: 1: 250,000

In the Municipality of Caratinga, it occupies precisely the northeastern portion of the municipality, with the lowest part having an altitude of 564 meters and the highest 916 meters, its lowest altitude is located near the junction that leads to the Municipality of Piedade de Caratinga on the banks of BR - 116 and the highest in the watershed of the Ribeirão da Laje hydrographic basin with approximately 912 meters.

According to the Köppen classification (1948), the climate of the study area is tropical highland Cwa with dry winter and humid summer with temperatures in the hottest months above 22º C. Annual precipitation is 1,196 mm with an average annual temperature of 22º C.

Because the microbasin is located in the Caratinga River basin, climate, annual precipitation and temperature data were used.

The banks of the watercourses no longer have riparian vegetation and are occupied by residences, brickworks and pigsties, in addition to small plantations of perennial crops, leaving only a small strip of less than 25 meters of the banks to be protected and recovered.

Throughout the micro-basin, the presence of native vegetation is almost insignificant, with banana and eucalyptus plantations, vegetables and pasture areas that have not been used for a long time predominating.

The springs and recharge areas are devoid of protection and vegetation cover and along the watercourses dams for fish farming, irrigation and brick manufacturing activities have been compromising the water resources of the hydrographic microbasin day after day, further highlighting the lack of environmental licensing and regularization of the activities of the Córrego Seco microbasin, Caratinga, MG.

To produce the work, the creation of a database and computational tools was of fundamental importance. Precipitation and evapotranspiration data were collected at the Caratinga Meteorological Station of the Ministry of Agriculture, Livestock and Supply and were used to calculate the water balance. The SPRING and ArcGis software were used to create the location map of the Córrego Seco river basin.

2.1 Calculation for storage

To calculate the water balance of the Córrego Seco hydrographic microbasin, the Thornthwaite-Mather methodology (1955) was used.

In the case of the microbasin, 130 mm of storage was defined for the month of January to begin the calculation, where the storage value for the remaining months of 2018 was calculated with equation (1);

$$.ARM\ (ABR): ARM\ (MAR) + (P - ETP)\ (ABR) \quad (1)$$

Where:

ARM: Storage

P: Precipitation

ETP: Potential evapotranspiration

ABR and MAR: Abbreviations for the months of April and March.

2.2 Calculation for actual evapotranspiration

The calculation of real evapotranspiration was used in equation (2):

$$ETR\ (ABR) = P\ (ABR) + \ |\ ALT\ (ABR \quad (2)$$

Where:

ETR: Real evapotranspiration

P: Precipitation

ALT: Change in storage, always in module, as it will always be positive.

ABR: Abbreviation for the month of April

2.3 Calculation for storage change

To calculate the storage change, equation (3) was used:

$$.ALT\ (ABR) = ARM\ (ABR) - ARM\ (MAR) \quad (3)$$

Where:

ALT: Storage change

ARM: Storage value

ABR and MAR: abbreviations for the months of April and March.

2.4 Calculation for water deficiency

Equation (4) was used for the deficiency calculations:

$$.DEF\ (ABR) = ETP\ (ABR) - ETR\ (ABR) \quad (4)$$

Where:

DEF: Deficiency

ETP: Potential evapotranspiration

ETR: Actual evapotranspiration

ABR: Abbreviation for April

2.5 Calculation for excess water

To calculate the excess, equation (5) was used:

$$.EXC\ (ABR) = (P - ETP)\ (ABR) - ALT\ (ABR) \quad (5)$$

Equation used for storage equal to 130 mm, where:

EXC: Excess

P: Precipitation

ETP: Potential evapotranspiration

ALT: Storage change

ABR: Abbreviation for April

2.6 Calculation of storage value

The calculation of the storage value was performed using equation (6).

$$.ARM\ (OUT) = ARM\ (SET) + (P - ETP)\ (OUT) \quad (6)$$

2.7 Calculation for accumulated negative

For the accumulated negative, equation (7) was used:

$$.NEG.AC\ (ABR) = NEG.AC\ (MARÇ) + (P{+}ETP)(MAR) \quad (7)$$

Where:

NEG.AC: Accumulated negative

P: Precipitation

3 Results

Table 2 presents all the water balance data for the Córrego Seco microbasin based on precipitation and evapotranspiration data provided by the Caratinga Meteorological Station-MG, corresponding to monitoring from January 2018 to December 2018.

It is observed that from January to April there is very high rainfall and from May to November there is a drastic reduction and only in December there is a significant volume, although the months with the highest rainfall correspond to summer and the months with the lowest rainfall correspond to winter, which characterizes a wet summer and a dry winter.

The annual precipitation volume was 1,209.8 mm, the months with the highest rainfall occurred in January, February, March, April and December, totaling 974.8 mm, and the lowest rainfall occurred in the months of May, June, July, August, September and October, totaling 235 mm. All calculations were performed using the Thornthwaite-Mather method, for 130 mm of storage capacity.

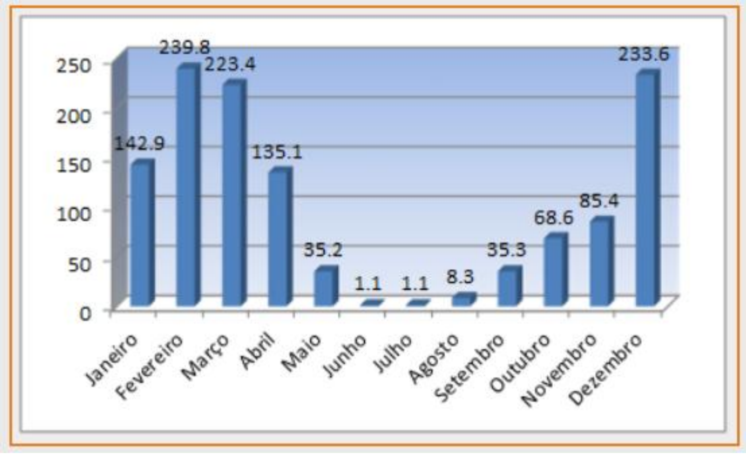
Table 2. Result of water balance calculations using the Thornthwaite-Mather method, 1955, for 100 mm of storage capacity

Col1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11
Mês	P	ETP	P – ETP	Pos Acum	NEG.AC	ARM	ALT	ETR	DEF	EXC
JAN	142,9	131,7	11,2	11,2	0	130,0	130,0	131,7	0	0
FEV	239,8	75,5	164,3	164,3	0	130,0	0	75,5	0	164,3
MAR	223,4	80,8	142,6	142.6	0	130,0	0	80,8	0	142,6
ABR	135,1	73,6	61,5	61,5	0	130,0	0	73,6	0	61,5
MAI	35,2	72,4	-37,2	0	-37,2	97,6	-32,4	-69,6	142,0	0
JUN	1,1	62,1	-61,0	0	-61,0	61,0	-36,6	-97,6	159,7	0
JUL	1,1	95,8	-94,7	0	-94,7	4,5	-56,5	-151,2	247,7	0
AGO	8,3	104,0	-95,7	0	-95,7	2,1	-2,4	-98,1	202,1	0
SET	35,3	125,4	-90,1	0	-90,1	1,0	-1,1	-91,2	216,6	0
OUT	68,6	135,7	-67,1	0	-67,1	0,6	-0,4	-67,5	203,2	0
NOV	85,4	117,3	-31,9	0	-31,9	0,5	-0,1	-32,0	149,3	0
DEZ	233,6	103,1	130.5	130,5	0	130	129,5	103,1	0	1,0
	∑1.209,8	∑1.177,3	∑32,4	∑510.1	∑-477,7	∑817,3	∑129,0	∑-142,5	∑1.320,6	∑369,4

Source: Authors (2019).

3.1 Precipitation

Regarding precipitation, the month with the highest rainfall index occurred in February, 239.8 mm higher than all the months combined with the lowest rainfall in the river basin, as can be seen in Graph 1. Based on the precipitation data represented in Graph 1, it is possible to plan agroforestry activities in the microbasin without incurring financial or environmental losses or water shortages.



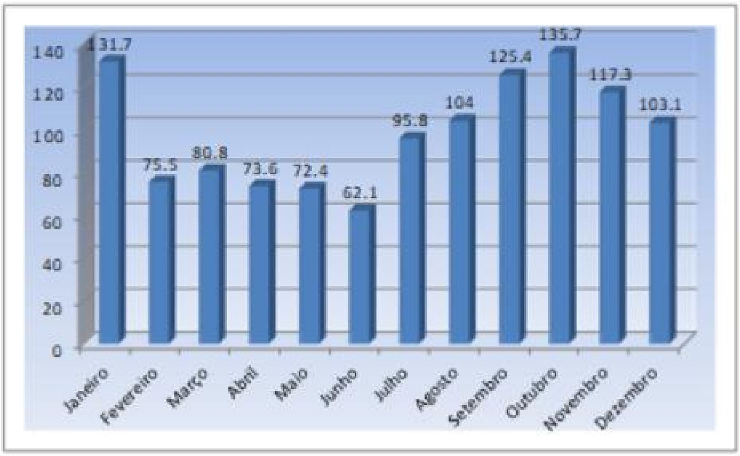
Graph 1. Precipitation in (mm) of the Córrego Seco hydrographic microbasin in 2018.

Source: Authors (2019).

3.2 Potential evapotranspiration

The potential evapotranspiration was represented in Graph 2. The data was acquired from the Caratinga Metrological Station where it can be observed that the greatest discrepancy occurred in the months of June, July and August where evapotranspiration was 62.1; 95.8 and 104.0 mm and rainfall of 1.1; 1.1 and 8.3 mm with a negative deficit of 159.7; 247.7 and 202.1 mm. In this situation, it indicates that the precipitation was not sufficient to supply the potential evapotranspiration, therefore the water stored in the soil will be used by the plants and from the moment this storage reaches zero the water deficiency will be imminent.

Regarding potential evapotranspiration, it can be seen that in the months of May, June, July, August, September, October and November, evapotranspiration was higher than precipitation, thus resulting in a considerable water deficiency. This data can be used in the micro-basin before cultivating certain types of crops.



Graph 2. Potential evapotranspiration in (mm) of the Córrego Seco hydrographic microbasin in 2018

Source: Authors (2019).

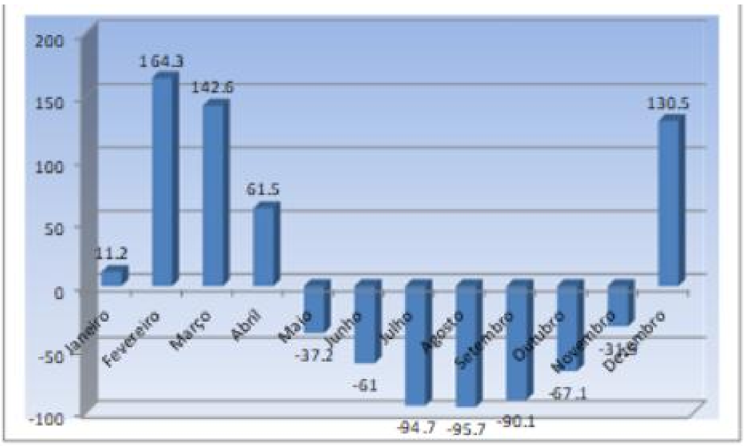
3.3 Difference between precipitation and evapotranspiration

The calculations made from the difference between precipitation and potential evapotranspiration, as can be seen in Graph 3, demonstrate that positive values occurred when precipitation was greater than potential evapotranspiration, and this surplus will supply the soil until its saturation, thus constituting a surplus that in turn will percolate or flow into watercourses.

The positive surplus of precipitation over evapotranspiration occurred in the months of January with 11.2 mm, February 164.3 mm, March 142.6 mm, April 61.5 mm, and December 130.5 mm.

The precipitation deficit over evapotranspiration occurred in the months of March -37.2 mm, June -61.0 mm, July -94.7 mm, August -95.7 mm; September -90.1 mm, October -67.1 and November -31.9 mm, with the lowest values occurring in July -94.7 mm and August -95.7 mm.

Negative values indicate that precipitation did not exceed potential evapotranspiration, in which case soil water storage will be reduced and when it reaches zero, water deficiency will be inevitable.

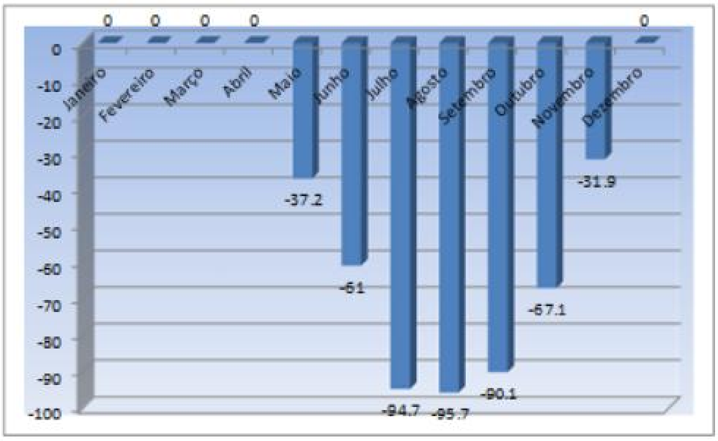


Graph 3. Difference between precipitation and evapotranspiration in (mm) of the Córrego Seco hydrographic microbasin in 2018

Source: Authors (2019).

3.4 Accumulated negative

The accumulated negative is the result of the residual storage of the accumulated negative values of (P-ETP) for water storage capacity in the soil, and for the microbasin a storage capacity of 130 mm was adopted. The accumulated negative was zero in the months of January, February, March, April and December, as the storage value reached its peak, in the other months the accumulated negative was between -31.9 mm in the month of November and -95.7 mm in the month of August, as shown in Graph 4.

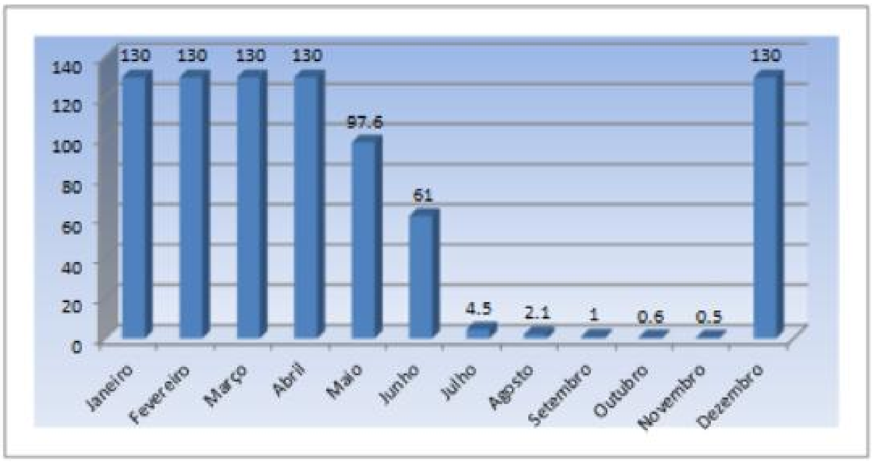


Graph 4. Accumulated negative for soil water storage capacity of 130 mm for the Córrego Seco watershed

Source: Authors (2019).

3.5 Soil water storage - ARM

Water storage in the soil of the Córrego Seco hydrographic microbasin can be observed in Graph 5, where storage occurred in all months of 2018, ranging from the lowest index in November with 0.5 mm, October 0.6 mm, September 1.0 mm, August 2.1 mm and July 4.5 mm and the highest indexes with around 130 mm in the months of January, February, March, April and December.

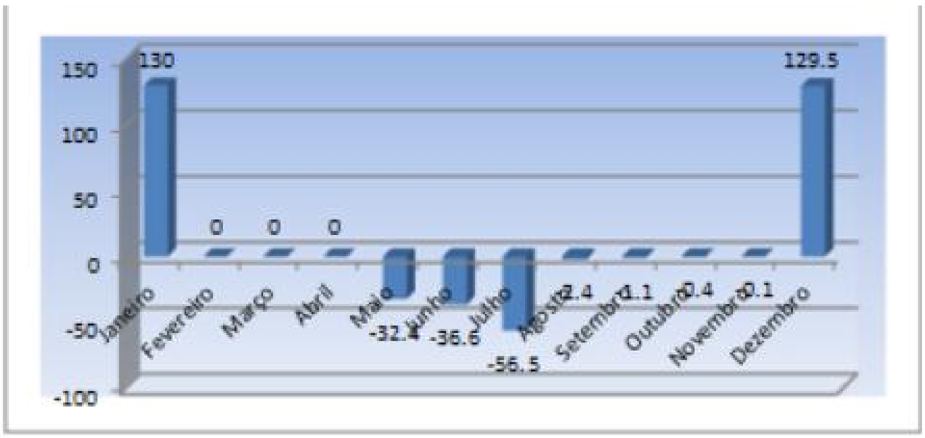


Graph 5. Water storage in the soil of the Córrego Seco Hydrographic Microbasin

Source: Authors (2019).

3.6 Changes in soil water storage - ALT

Only the months of January and December had water storage in the soil, being 130.0 mm and 129.5 mm respectively, and the other months from March to November saw a decrease in water stored in the soil, as shown in Graph 6.



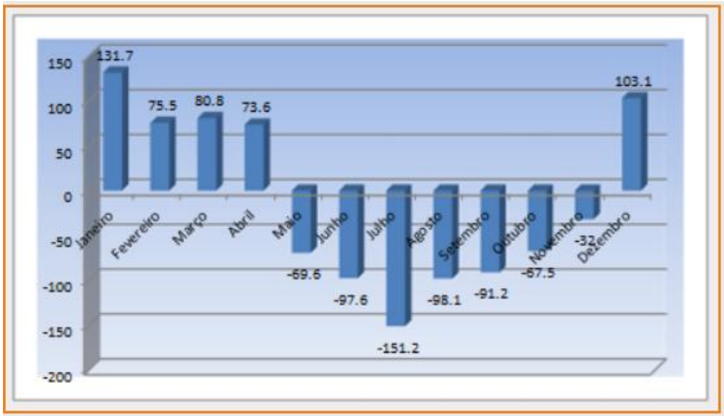
Graph 6. Changes in soil water storage in the Córrego Seco watershed

Source: Authors (2019).

3.7 Actual evapotranspiration

Actual evapotranspiration is equal to potential evapotranspiration as long as the storage value is not zero. When the storage value is zero, actual evapotranspiration will be calculated by adding precipitation to the storage change value.

As can be seen in Graph 7, actual evapotranspiration was equal to potential evapotranspiration in the months of January to April and in the month of December. In the months of May to November, actual evapotranspiration was below potential evapotranspiration.



Graph 7. Actual evapotranspiration of the Córrego Seco hydrographic microbasin

Source: Authors (2019).

3.8 Soil water deficiency - DEF

Graph 8 shows the monthly totals of soil water deficiency. It is known that this occurs when the storage value is zero. Soil water deficiency is equal to the difference between potential evapotranspiration and actual evapotranspiration.

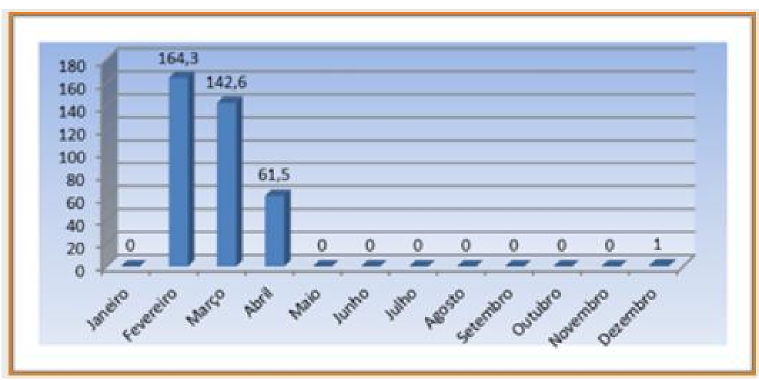
The soil water deficiency occurred in the months of January to April and December when the storage value was zero, and in the month of July the deficiency reached 247.7 mm as shown in Graph 8.

Graph 8. Water deficiency in the soil of the Córrego Seco watershed

Source: Authors (2019).

3.9 Excess water in the soil

The excess water value in the soil occurs when the maximum storage value is reached. The excess water in the soil in the Córrego Seco microbasin occurred only in the months of February, March, April and December, as shown in Graph 9.



Graph 9. Surplus water in the soil of the Córrego Seco watershed

Source: Authors (2019).

4 Final considerations

The study of the water balance of the Córrego Seco hydrographic microbasin carried out using the Thornthwaite-Mather method, 1955, had good efficiency in the results which will allow for more cautious management of water resources.

The water balance calculations allowed us to assess that the months in which the deficit occurred were concentrated from May to November and the highest rainfall occurred in the months of July to April and December, with the maximum peak rainfall in February in 2018, demonstrating that the area studied has two well-defined seasons.

Water balance calculations for a hydrological microbasin are fundamentally important tools that can be applied to the safe and orderly use and occupation of land and to the sustainable management of water resources in a basin or microbasin.

With the data obtained from water balance calculations, it is possible to guide the basin's inhabitants on the best way to carry out their agroforestry and industrial activities, without losses, providing sustainability and avoiding possible conflicts related to water resources.

It is suggested that the methodology applied in this research be used for other micro-basins, as it is simple, easy to acquire data and execute, obtaining expressive and reliable water balance data.

Conflicts of interest

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

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