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Modeling the Water Balance in the Micro Basin of the Region of Tabuleiro Costeiro, Brazil

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Abstract: The research was developed in the Rural Campus of the Sergipe Federal University in São Cristóvão, city of Sergipe state, in a place characterized by its predominant coverage of the Atlantic Forest and soil constituted by a Red and Yellow Argisoil with extension of 32 ha. The research collected climate data on purpose to model the main components for a water balance of the micro-basin, which were evaluated precipitation, runoff, evapotranspiration and soil water storage. During the period that lasted from September 1, 2017 to May 31, 2018, 1003.22 mm of rainfall and only 11.01 mm of runoff were recorded, showing the importance of evaluating evapotranspiration and the effects caused by the vegetation's type cover. The modeling was done daily and soil water storage was estimated through the water balance. At the end of the study, the participation of evapotranspiration was intense, due to the climatological characteristics of the region, representing 82.4% of the amount of precipitated water, which is evidenced by the low recorded value of runoff.

Key words: forest hydrology, coastal board, watershed's management

1. Introduction

Used for human consumption and for socioeconomic activities, it is withdrawn from rivers, lakes, dams, and aquifers, having a direct influence on health, quality of life and development of populations, water is one of the primary need for life, resource indispensable for the human being and the whole life of the planet. The availability of this resource is directly linked to species survival and socioeconomic development of countries.

The scarcity of this resource is becoming an increasingly common phenomenon. This is a result of increasing urban and industrial demand and increased waste production due to the incorrect use of water. The quality and quantity of water in a river basin can be hampered by several factors, including: management, climate and vegetation cover.

The hydrological cycle involves the physical processes of evaporation, transpiration, precipitation, infiltration, percolation, subsurface runoff, and surface runoff, which represent the different paths through which water circulates in the three phases of the Earth system: hydrosphere, lithosphere and atmosphere [12]. The water movement form of a river basin is linked to characteristics such as its shape, topography, area, geology, drainage network, soil and the type of vegetation cover. The area bounded by a contour within which all precipitated water when it is not evaporated, infiltrated or retained, flows to that point [6] is defined as a river basin. The hydrographic basin is the best representative for the integrated planning of natural resource management in the ecosystem, it involves and can be defined as the physiographic area drained by a system of connected watercourses converging to a bed or surface water [6].

The natural supply of water for a given region is dependent on the hydrological cycle. Thus, the

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importance of understanding how and in what quantity the water travels through all the stages of its cycle, considering water as essential material for the maintenance of life. Due to this importance of climatological water balance and climatic classification for all the areas of study involved, it is necessary to record and analyse the data of the main components of the water balance of the Tabuleiro Costeiro region of Brazilian's Northeast, so the proposal presents a fundamental return, the evapotranspiration of the native culture of this watershed taking into account the climatic conditions of the coastal region.

2. Literature Review

The complexity of the study of water behaviour becomes high due to the factors involved such as soil characteristics and vegetation. These factors are changeable over time and have irregular behaviour, therefore, however precise the mathematical model, it is necessary to confront the data with reality due to the mutability of several factors [6]. During the water cycle, their infiltration, redistribution, evaporation and water absorption by plants are interdependent processes and, most of the time, occur simultaneously. To study the water cycle, it is necessary to consider the water balance. According to Pereira et al. [2], water balance is the way to account for and monitor the amount of water stored in the soil and is the result of applying the principle of mass conservation to water in a volume of vegetated soil. This is nothing more than the sum of the amounts of water entering and leaving an element of soil volume and, in a given period of time, the result is the net quantity of water that remains available to the plants [7].

The elements of precipitation and evaporation are considered to be the most important for the hydrologic cycle. In the municipality of Balsas, in the state of Maranhão, a high evapotranspiration potential was observed, where the average annual rate is 1720 mm and for annual rainfall of 1175 mm, being classified as a hot and humid tropical climate region by Passo et al. [9].

In a similar study, carried out in the region of Minas Gerais and with vegetation cover characteristic of Atlantic forest, using the same mathematical model (Penman-Monteith), the result founds were: "In terms of water balance, evapotranspiration corresponded to 89% of the total precipitate, deep drainage at 13.6% and storage variation was slightly negative during the analysis period" by Pereira [2].

The balance must be complexity defined by the size of the basin to be studied and the type of study must also be taking into consideration (the end that will take the result of water balance), some values that could not be accounted for in large basins in a large variation of time, with the decrease of the study area, the other factors become more relevant for their study, so, on a small scale, it would be interesting to analyse the interception, infiltration, percolation and surface runoff, which are significant for small areas and are very relevant for understanding of hydrological processes. In the meantime, that is, between the occurrence of precipitation and the output flow of the basin, all the other processes, composing the hydrological cycle, it happens. Silva et al. [12] also show the great difference in the type of model to be adopted and that the alteration of the balance model for its region brought an increase in annual evapotranspiration from 803 to 1298 mm in the Rio Doce region.

In the Ribeirão Marcela Hydrographic Basin, in a study whose objective was to analyse the water recharge, the most influential component in the water balance is evapotranspiration, with its participation of 56.7% of precipitation in the general average by Pontes et al. [8], then even without characterizing all the factors, classifying the main elements of the water balance brings good approximations for the study of water balance in watersheds. The different uses of water by the resident population in the basin, such as water abstraction for domestic supply, leisure use, bathing, sewage disposal, and industrial effluents can still occur [1].

The acquisition of the results of the variables of the balance sheet has a variation with climate change, topography, and soil type. Brandão et al. [4] discuss the interference of vegetation cover for the climatic classification in the Northwest of Rio de Janeiro “it is necessary besides the analysis of the elements of the climate, to evaluate the history of the soil uses in a certain area or place”, he goes on to explain “Past and present transformations in the physical environment can lead to sensitive changes in water balance, precipitation, and temperature” and concludes “transformed the exuberant Atlantic forest through a scenario similar to the semi-arid Northeast” [4].

Papers as by Martin et al. [11] show the importance of water balance and climatic classification for all areas of study involved and what the need to record and analyse the data of the main components of the water balance. The author, through the data of recorded climate, brings the simulation of soybean plantations in 33 regions of the state of São Paulo and some municipalities of nearby states, determining the best locations for soybean cultivation in the states of São Paulo.

In a study carried out to determine the precipitation reduction and moisture transport of the Amazon basin. Having a greener judgment according to Silveira et al. [8]: “If human activities do not allow that there is environmental regeneration, climate-vegetation balance will be affected, leading to a warmer condition and dry, which in turn, will have serious consequences for the ecosystems of the Amazon”. In the case of the Tabuleiros Costeiros region of North-eastern Brazil, the proposal presents a fundamental return, the evapotranspiration of the native culture of this watershed considering the climatic conditions of the coastal region and the climatic classification.

3. Methodology

To accomplish the objective of model the water balance of the micro-basin was necessary before to instrument her and evaluate the parameters. So was delimitated the contour of de area, as well installed the necessary tools.

3.1 Area of Study

The study was conducted in the watershed of the Federal University of Sergipe (UFS), located in the Rural Campus of the institution, in São Cristóvão - SE, between the coordinates 10°55'38"and 10°56'00" South and 37°12'21"and 37°12'00" West (Fig. 1). The basin has an approximate area of 32 ha with a mild topography, with an average annual air temperature of 28°C and an average annual rainfall of around 1200 mm.y^{-1} and an average altitude of 150 m. Its coverage is predominantly Atlantic Forest (~80%). With characteristic soils Red and Yellow Argisoil.

3.2 Surface Runoff

In order to calibrate the spillway’s linigraph was made field measurements (Fig. 2). The method adopted on the field was to determine how much volume was flowing in a fixed time in several repetitions and then obtain a good approximation of mean for the readings of the equipment. Thus, through Eq. (1) it was possible to determine the flow rate consulted in the apparatus at the moment the measurements were collected.

$$Q = V.t^{-1} \tag{1}$$

where, Q is the flow, in m³ s-1; V, is the volume, in m³, and t, the time, in s.

Knowing that the spillway has a triangular shape with a 90º angle, knows the required height water for

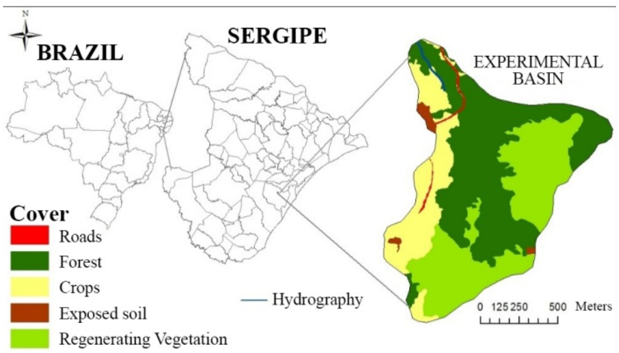

Fig. 1 Location of the study area.

Fig. 2 Calibrating the linigraph in the field for flow measurement.

the surface runoff measured in the field in that schedule, so the equipment was calibrated.

The conversion of factors is only a matter of physically analysing their meaning, so knowing that the humidity is given in a percentage of water quantity, multiply by the depth that the value represents in millimeters.

The runoff through the flow rate only brings the simple assumption that: all water that did not infiltrate in the area above the spillway descends through the spillway dam, and can then be read by the linigraph and transformed into millimeters by manipulating Equation (1) as follows:

$$Q = V.t^{-1}, \text{but } V = A.h*1000$$

where, Q is the flow, in m^3 s-1; V, is the volume, in m^3, and t, the time, in s, A is the basin area in m^2, the surface water in mm and 1000 is the conversion factor from meters to millimeters.

The area that will be used is the area above the spillway within the micro-basin of was delimited in 32 ha. For coherence the time for transformation of the flow in this formula must be equal to the humidity measurement intervals and thus, through Eq. (2), determine the evapotranspiration of the crop.

3.3 Water Storage in Soil

The other equipment to be calibrated is Diviner 2000®, Sentek Pty Ltda., Australia, which makes an indirect measurement for soil humidity. The equipment works as a capacitive probe, does not come into contact with the ground and measures the humidity at various depths. As a capacitive probe, the Diviner does not measure the humidity level, but rather the capacitance resulting from the medium of water, air, and soil, and must be calibrated for each type of soil, since the composition of each soil changes its conductivity. Thus, to calibrate it, only the actual soil moisture and its measurement are necessary to relate them and determine how much each measurement made on the apparatus is worth. For more precision, soil sampling (Fig. 3) was used to measure moisture when it was approximately saturated when the soil was filled with water, and another was made near the wilting point, dry soil.

Although not calibrated, humidity measurements are still made in capacitance, since the data is stored in the device itself and can be downloaded at any time, so the conversion can be done when the actual data is available. Periodic data are collected from 7 points ranging from 50 to 80 cm in depth, which were chosen over the spillway so that they could be reconciled to the soil humidity and runoff data with the area above the spillway and at different altitudes, near and far from the water stream so that data could be generalized for the whole region.

Fig. 3 Collecting soil humidity data.

3.4 Precipitation

The climatological station used in the study was the E5000 Meteorological Station, Irriplus, which measured the precipitation of the region from the beginning of September 2017 until May 2018 and was also responsible for monitoring the other weather data used in this paper. Based on these factors will be developed Eq. (2) of basin water balance.

3.5 Evapotranspiration

Evapotranspiration potential (Et0) is calculated by daily means of climatic data (precipitation, wind speed, radiation), this is the evaporation due to the transpiration of a completely covered surface of a reference culture (normally grass in full growth without water restriction, with reduced climatic stresses), being then a meteorological variable that is expressed from the climatic conditions. The method used to estimate Et0 will be Penman-Monteith, using the software ET0 Calculator from FAO.

Given that the weather conditions are not always ideal for the growth of vegetation, the value found in Et0 is multiplied by a correction factor, called Kc, which varies from culture to culture. The multiplication of Et0 with Kc determines the actual evapotranspiration (Etr). Therefore, since the Kc value for the native forest of the watershed region is unknown, it will be the variable analysed in Eq. (2) of the water balance.

3.6 Water Balance

From the data collected in the field during this period you can generate a precipitation \ surface runoff balance, so, with all the variables already measured is possible to estimate the Kc culture and an estimation of results by comparing the results obtained in other jobs or situations where the Kc would be from cultures simulating, for example, the transformation of the area into a rural property.

$$P = ET + ES + \Delta R. \quad (2)$$

where, P is the precipitation, in mm, ETR is the actual evapotranspiration, in mm, ES is the surface runoff, in mm, and ΔR is the soil humidity difference in a time period in mm.

4. Analyses and Result

The data presented by the micro-basin during the period from September 2017 to May 2018 were: total precipitation of 1003.22 mm, with a mean of 0.15 mm daily in that period, with a maximum of 20.33 mm on October 18th, 2018, with periods of low rainfall in November and December 2017 and January 2018. Potential Evapotranspiration (Et0) recorded was 826,60 mm, and surface runoff was 11.01 mm. The distribution of these factors throughout this period are presented in Figs. 4, 5 and 6.

The Et0 score average was 91.4mm during the study period, with a maximum of 5.2 mm on January 1th 2018, with high monthly values where radiation has greater intensity, combined with low humidity values.

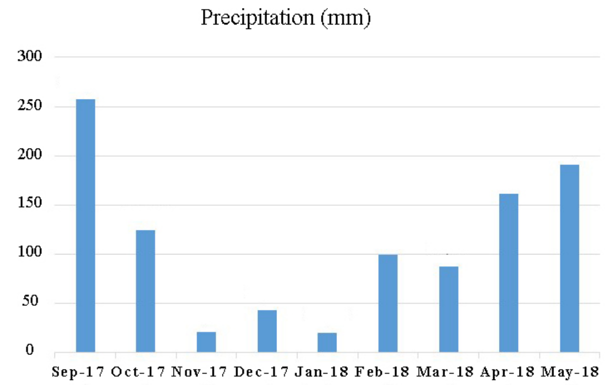

Fig. 4 Precipitation distribution graph.

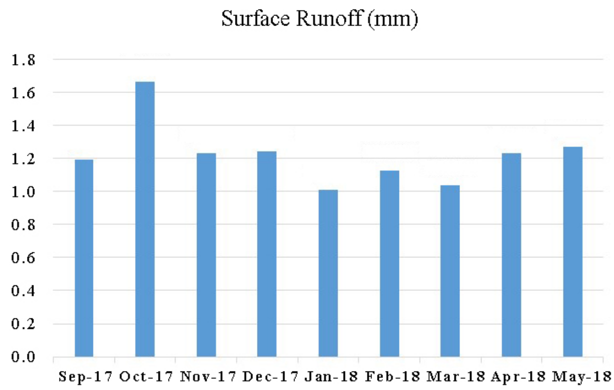

Fig. 5 Runoff distribution graph.

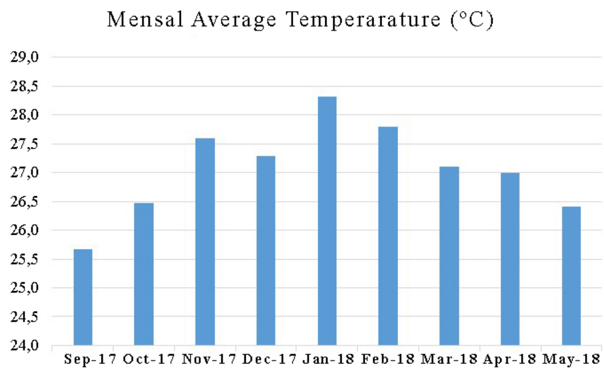

Fig. 6 Mensal average Temperature graph.

The relationship of climate data is in Table 1 and the illustration of the Et0 distribution in the graph of Fig. 7.

With a total volume of 11.01 mm in the period, the spillway did not present dry periods, having a maximum and minimum of 0.14 mm on October 18th, 2017, and 0.01 mm on January 10th, 2018, respectively. It is possible to observe how the basin responds almost immediately in the relation of runoff and precipitation in the graph of Fig. 9.

The micro basin also had a mean temperature of 27.4°C, with a maximum value of 42.8°C and on March 28th, 2018 and a minimum of 20.1°C on September 30th, 2017. Fig. 8 shows how the temperature varies in this period by relating it to the mean temperature, as well as the intrinsic relationship of the Et0 with the micro-basin temperature in the graph of Fig. 10.

Table 1 Climate date and monthly Et0.

	Sep. 17	Oct. 17	Nov. 17	Dec. 17	Jan. 18	Feb. 18	Mar. 18	Apr. 18	May. 18
Wind speed (km/month)	12.96	15.03	21.61	21.44	14.59	18.51	17.18	8.32	7.26
Temp. (ºC)	25.7	26.5	27.6	27.3	28.3	27.8	30.5	30.3	30.4
Humidity (%)	85.92	86.43	83.94	83.65	76.90	83.69	74.08	60.40	84.16
Rad. (MJ/m².day)	385.70	443.85	488.99	463.59	335.49	395.44	449.88	385.55	359.31
ETP (mm)	80.50	93.00	106.60	100.30	102.90	86.80	99.70	78.60	78.20

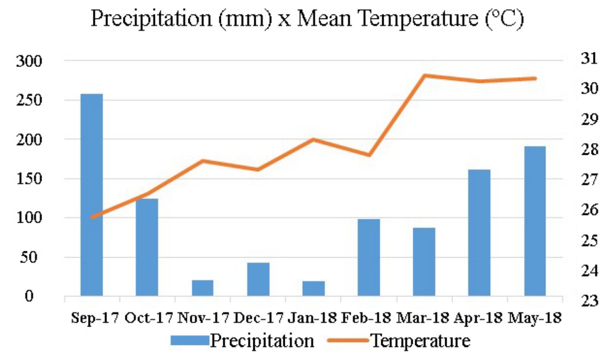

Fig. 8 Relation between precipitation temperature.

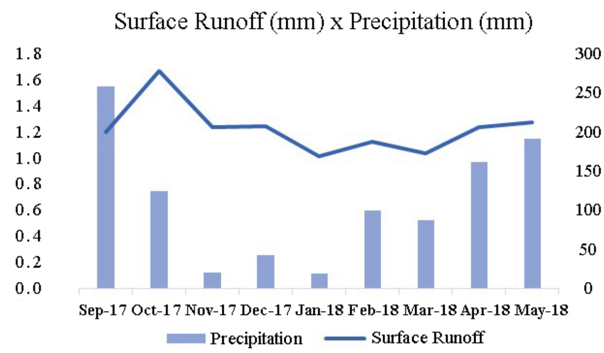

Fig. 9 surface runoff altering according to precipitation.

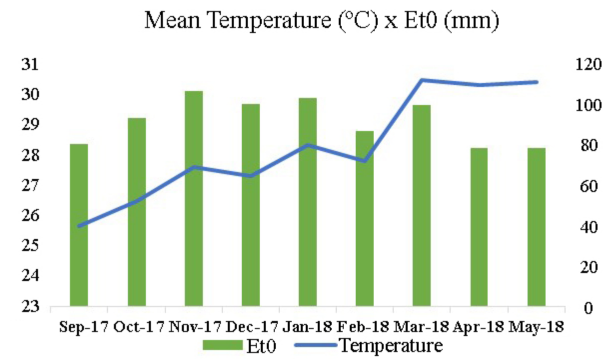

Fig. 10 Variation of ETP with an average score of temperature.

The Et0 has 82.4% of the precipitation value and the flow of 1.1% of the same. To determine the Kc in a micro basin with the dimensions of this studied, we would have that the best possibility, would be to relate also the participation of the humidity in the soil. However, in order to simplify the model of the basin at the present moment, we can consider Et0 in Eq. (2), since soil humidity variation does not yet present concrete data due to the unavailability of the relationship between soil capacitance and its moisture due to its characteristics. However, through Equation (2) of the model followed, the soil water storage can be estimated in a simply by considering the Et0 equals Etp, taking as reference previous papers, where this value of the parameter represents great amount of the water balance, as Pereira [2]. The soil water storage is represented in the graph of Fig. 11.

In the Fig. 12 have a representation of the variation of soil storage water and the surface runoff in a daily interval, showing clearly how the micro-basin responses at rain effects.

5. Conclusion

Thus, Et0 results in 82.4% of the precipitation value, and the surface runoff of 1.1% of the precipitation, which was 1003.22 mm recorded in this period of 273 days, is in agreement with the expected results for this coverage, in view of similar work. In this way, the timber micro-basin of the Timbó river is characterized

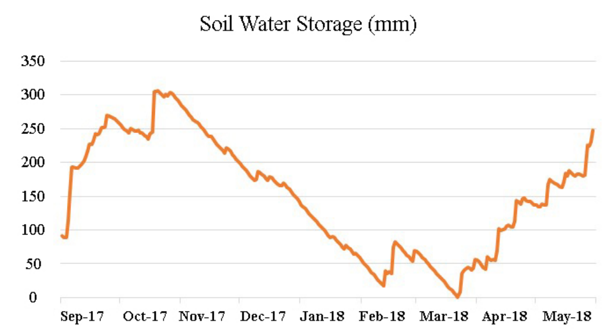

Fig. 11 Soil water availability graph.

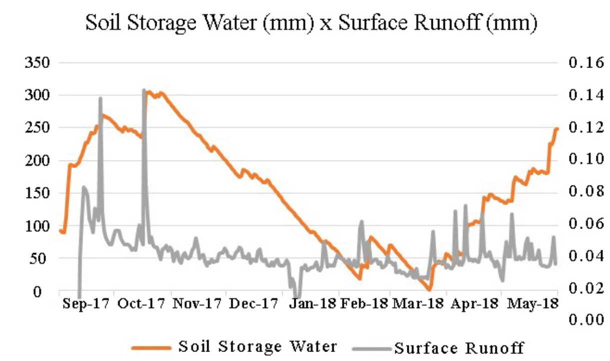

Fig. 12 Relation flow and storage.

by small surface runoffs due to the intense use of water in the soil by the forest, which preventing large floods from occurring. This soil can retain in itself large amounts of water, caused by him type, having a significant amount of humidity for forest use for a large period. And this demonstrates the importance of the type of vegetation cover and the importance of the native forest preservation from this response in a providential way to the maintenance of the water cycle and the preservation of the climate.

This work will be extended for another 2 years, storing the results in a database that at the end of the period will be used to determine the climatic classification of the watershed.

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