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WATER BALANCE IN HAPLIC CAMBISOLS UNDER FOREST AND PASTURE IN THE BONFIM WATERSHED: MOUNTAINOUS REGION OF RIO DE JANEIRO STATE

Ana Claudia de Mello Nascimento[1]
Wenceslau Geraldes Teixeira[2]
Alexandre Ortega Gonçalves[3]
Alfredo Akira Ohnuma Junior[4]

ABSTRACT

Objective: To estimate the water volumes of the main components of BH in a Haplic Cambisol in forests and pastures in the Bonfim River basin, mountainous region of RJ.

Theoretical framework: The water balance (BH) accounts for the volumes of water input and output in a given space (Haplic Cambisols under forests and pastures).
Method: The study period was 01/01/2000 and 12/31/2019. The HYDRUS-1D model was used to estimate water volumes in BH. Pedotransfer functions were used to determine the physical water parameters of water retention and conduction in the soil. The daily precipitation and evapotranspiration data were considered upper boundary conditions, and the lower boundary conditions were considered free drainage. Water absorption by the roots was considered as the additional factor (Sink factor) in the soil water mass balance.

Results and conclusion: The average annual precipitation was 1462 mm and the potential evapotranspiration was 1026 mm. In lhe area under pastures: 83%, 7% and 9% of the total precipitated and percolated, transpired and evaporated, respectively. In areas under forests: these values were 43%, 51% and 6%. In the dry season, evapotranspiration was 20% of the total precipitation in the forest area and 8% in the pasture areas. Percolation in the dry season was 17% of the total precipitation in the pasture and 7% in the forest. In the rainy season the percolated values were 66% in the pasture and 36% in the forest.

Implications of the research: Knowing the volumes of water in the components of the BH can help in decisions regarding the organization of land use and cover systems in basins of the Atlantic Forest biome. Changing soil use and cover systems alters the volumes of water percolated or evapotranspired.

Originality/value: Estimating the water volumes in the BH components in pasture and forest allows predicting the effects of climate change and land use and their consequences.

Keywords: Water Availability, Water Balance, Land Use and Cover, Pastures, Forests.

BALANÇO HÍDRICO EM CAMBISSOLOS HÁPLICOS SOB FLORESTAS E PASTAGENS NA BACIA HIDROGRÁFICA DO BONFIM: REGIÃO SERRANA DO ESTADO DO RIO DE JANEIRO

RESUMO

Objetivo: Estimar os volumes de água dos principais componentes do BH num Cambissolo Háplico em florestas e pastagens na bacia do Rio Bonfim, região serrana do RJ.

[1]Universidade do Estado do Rio de Janeiro (UERJ), Rio de Janeiro, Rio de Janeiro, Brasil.
E-mail: anaclaudia.mello@hotmail.com Orcid: https://orcid.org/0009-0001-2050-931X
[2] Embrapa Solos. Rio de Janeiro, Rio de Janeiro, Brasil. E-mail: wenceslau.teixeira@embrapa.br
Orcid: https://orcid.org/0000-0002-2010-6078
[3] Embrapa Solos, Rio de Janeiro, Rio de Janeiro, Brasil. E-mail: alexandre.ortega@embrapa.br
Orcid: https://orcid.org/0000-0003-0709-9018
[4] Universidade do Estado do Rio de Janeiro (UERJ), Rio de Janeiro, Rio de Janeiro, Brasil.
E-mail: akira@eng.uerj.br Orcid: https://orcid.org/0000-0002-0772-9334

Referencial teórico: O balanço hídrico (BH) contabiliza os volumes de entrada e saída de água em determinado espaço (Cambissolos Háplicos sob florestas e pastagens).

Método: O período de estudo foi 01/01/2000 a 31/12/2019. Foi utilizado o modelo HYDRUS-1D para estimar os volumes de água no BH. Funções de pedotransferência foram utilizadas para determinar os parâmetros físico hídricos da retenção e condução da água no solo. Consideraram-se condições de fronteira superior: dados de precipitação e evapotranspiração diários e condições de fronteira inferior: drenagem livre. A absorção da água pelas raízes foi considerada como o fator adicional (*Sink factor*) no balanço de massa da água no solo.

Resultados e conclusão: A precipitação pluvial média anual foi de 1462 mm e a evapotranspiração potencial de 1026 mm. Na área sob pastagem: 83%, 7% e 9% do total precipitado foram percolados, transpirados e evaporados, respectivamente. Na área sob floresta: esses valores foram de 43%, 51% e 6%. Na estação seca a evapotranspiração foi de 20% do total precipitado na área de floresta e de 8% na área de pastagem. A percolação na estação de seca foi 17% do total precipitado na pastagem e 7% na floresta. Na estação chuvosa os valores percolados foram de 66% na pastagem e 36% na floresta.

Implicações da pesquisa: Conhecer os volumes de água nos componentes do BH pode auxiliar nas decisões quanto ao ordenamento dos sistemas de uso e cobertura do solo em bacias do bioma Mata Atlântica. A mudança dos sistemas de uso e cobertura do solo altera os volumes de água percolada ou evapotranspirada.

Originalidade/valor: Estimar os volumes de água nos componentes do BH em pastagem e floresta permite prever os efeitos de mudança do clima e do uso do solo e suas consequências.

Palavras-chave: Disponibilidade Hídrica, Balanço Hídrico, Uso e Cobertura do Solo, Pastagens, Florestas.

BALANCE HÍDRICO EN CAMBISOLES HÁPICOS BAJO BOSQUE Y PASTIZAL EN LA CUENCA HIDROGRÁFICA DEL RÍO BONFIM: REGIÓN MONTAÑOSA DEL ESTADO DE RÍO DE JANEIRO

RESUMEN

Objetivo: Estimar los volúmenes de agua de los principales componentes de BH en un Cambisol háplico en bosques y pastizales de la cuenca del río Bonfim, región montañosa de RJ.

Marco teórico: El balance hídrico (BH) da cuenta de los volúmenes de entrada y salida de agua en un espacio determinado (Cambisoles háplicos bajo bosques y pastos).
Método: El periodo de estudio fue 01/01/2000 y 12/31/2019. Se utilizó el modelo HYDRUS-1D para estimar los volúmenes de agua en BH. Se utilizaron funciones de pedotransferencia para determinar los parámetros físicos del agua de retención y conducción en el suelo. Los datos diarios de precipitación y evapotranspiración se consideraron condiciones de límite superior y las condiciones de límite inferior se consideraron de drenaje libre. La absorción de agua por las raíces se consideró como el factor adicional (factor de sumidero) en el balance de masa de agua del suelo.

Resultados y conclusión: La precipitación media anual fue de 1462 mm y la evapotranspiración potencial fue de 1026 mm. En el área bajo pastos: 83%, 7% y 9% del total precipitado y percolado, transpirado y evaporado, respectivamente. En las zonas bajo bosque, estos valores fueron del 43%, 51% y 6%. En la época seca, la evapotranspiración fue del 20% de la precipitación total en el área forestal y del 8% en las áreas de pastoreo. La percolación en la época seca fue 17% de la precipitación total en la pastura y 7% en el bosque. En la época de lluvias los valores de percolación fueron de 66% en la pastura y 36% en el bosque.

Implicaciones de la investigación: Conocer los volúmenes de agua en los componentes del BH puede ayudar en las decisiones sobre la organización del uso del suelo y los sistemas de cobertura en las cuencas del bioma del Bosque Atlántico. Los cambios en el uso del suelo y los sistemas de cobertura alteran los volúmenes de agua filtrada o evapotranspirada.

Originalidad/valor: La estimación de los volúmenes de agua en los componentes de BH en pastos y bosques permite predecir los efectos del cambio climático y el uso del suelo y sus consecuencias.

Palabras clave: Disponibilidad de Agua, Equilibrio Hídrico, Uso y Cobertura del Suelo, Pastos, Bosques.

1 INTRODUCTION

Due to the increase in urbanization, population density and industrial expansion, the demand for water resources has been growing and often above availability, which ends up directly compromising the quality and quantity of water resources. The water balance (BH) corresponds to the accounting of the volumes of water input and output in a given volume of soil, climate, land use and cover systems and in a given time interval (Souza et al., 2015).

Estimates of water volumes in the different components of a BH in a river basin contribute to ascertaining the need to implement appropriate strategies for managing surface and subsurface water resources (Engelbrecht et al., 2019).

Land use and overuse, burning, soil compaction, pollution, and other actions directly interfere with the hydrological cycle. BH is one of the most effective tools for understanding the complexity of water resources associated with climate and the local physical profile (de Albuquerque et al., 2019). Understanding BH can also provide better agricultural planning, ensuring better crop development, productivity and water security (Villa et al., 2022), as well as drainage and irrigation practices. From the determination of the critical months (water deficits) it is possible to collaborate with the planning of agricultural activities (Silva Junior et al., 2018).

Villa et al. (2022) studies of BH with maximum input variables and long historical series, together with culture coefficients for calibrated evaporation estimates, are of great relevance. All elements of the HBS are interrelated. In vegetation areas rainfall directly influences transpiration, evapotranspiration and water interception by plants (Martinhago et al., 2021). For example, with decreasing rainfall volume, all other components follow the same trend. However, among all, transpiration is the least impacted, while interception in the hydrological cycle represents a very small portion in BH, regardless of the amount of rain (Martinhago et al., 2021).

Carvalho-Santos et al. (2016) the combined effects of climate change and land cover change can improve or degrade the provision of hydrological services. The use of BH partitioning to assess water-related ecosystem services is essential to underpin broad land use change decisions (Casagrande et al., 2021). The author points out that forests face significant threats due to change in land use, especially deforestation, and that conventional analyzes have focused on the direct benefits to humans, considering forests as water consumers due to interception and transpiration, however, the contribution of forests as water providers, through transpiration of the treetops, is often disregarded.

There is a scarcity of research on the impact of changes in land use on the water resources of the basins and hydrographic microbasins of the Atlantic Rain Forest (Rodrigues et al., 2021) and understanding the HB in these regions is a priority need (Guauque-Mellado et al., 2022; Rodrigues et al., 2021). Such understanding is essential to face the challenges of dry climate and should be considered in decisions related to the preservation or regeneration of areas within this biome (Guauque-Mellado et al., 2022). The HYDRUS-1D software (Šimůnek et al., 2008) is a finite element model for one-dimensional simulation of water, heat and multiple solute movements in various saturation media. The computational package mathematically solves the Richards equation for flow of water in the saturated and unsaturated zone, and convection-dispersion-like equations for transport of solute and heat (Šimůnek et al., 2016). The HYDRUS-1D model is able to describe the dynamics of the soil water content and fractionate the total evaporation into its independent components (Casagrande et al., 2021) and simulate the volume of water absorbed by plants by coupling information on the availability of water in the soil, with the evaporative demand of the atmosphere with physiological parameters and the capacity of certain plant species to absorb water from the soil, for example, using the Feddes model (Feddes & Zaradny, 1978).

In order for calculations of water flows to be carried out, by solution of Richard's equation, the hydraulic properties of water retention and conductivity must be provided for each soil layer considered, commonly using van Genuchten's equation (1980).

The Piabanha Hydrographic Region (RH-IV) formed by the watershed of the Piabanha River and the tributary basins of the Paraíba do Sul River. This area covers 3,460 km², equivalent to 5.64% of the total area of the Hydrographic Basin of Paraíba do Sul. The Piabanha River is 80 km long, and the RH-IV consists of 10 municipalities (AGEVAP, 2021). The Bonfim River, a tributary of the Piabanha River, rises in the National Park of Serra dos órgãos (PARNASO) and empties into the Piabanha River. Part of the water supply of the municipality of Petrópolis is taken from the Bonfim River (Pessoa, 2013). The Hallic Cambisols are one of the predominant soil classes in the studied area (Pereira et al., 2021). They are poorly developed soils, generally of low permeability, and occur in different environments, but mainly in areas of undulating to mountainous reliefs. In mountainous environments, they are usually shallow soils and have limitations for agricultural use and high susceptibility to water erosion (Zaroni

& dos Santos, 2021). In the region are under the use and occupation mainly of forest vegetation and pastures (Silva et al, 2013).

In the light of the above, the estimation of the water volumes of the components of the water balance is a tool of great importance for the management of water resources, and it is paramount to understand how the alteration of the use and coverage of the land associated with a given class can modify the hydrological cycle. The objective of the work was to determine the volumes of water of the main components of the water balance (BH), in two scenarios of use and cover of the land (pasture and forest), both under Cambissolo Háplico in the hydrographic basin of the Rio Bonfim - RJ.

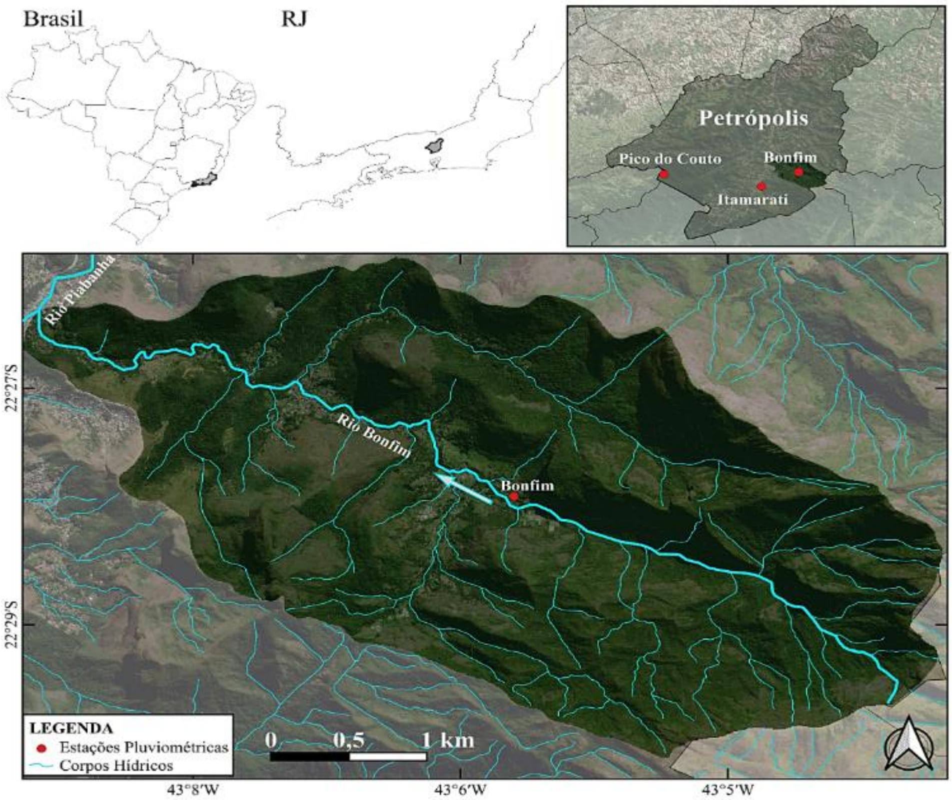
2 METHOD

2.1 FIELD OF STUDY

The study area is the catchment area of the Bonfim River, a tributary of the Piabanha River, and its biome is the Atlantic Rain Forest and it has a total area of 30 km². The course of the Bonfim River is geographically divided into high, medium and low (Lawall, 2010; Veloso, 2012). The basin is located in the second district of the municipality of Petrópolis, in the state of Rio de Janeiro (Figure 1).

Figure 1

Location map of the Bonfim river basin and rainfall stations - Rio de Janeiro-RJ



Source: IBGE, ANA and EMBRAPA cartographic base, map prepared by the authors

2.2 PREDOMINANT SOIL CLASSES AND SOIL PHYSICO-WATER PARAMETERS

The dominant soils in the Bonfim River basin are the Dystrophic Litholic Neosols and Dystrophic Tb-hallic Cambisols (Table 1).

Table 1

Summary of soil types distributed along the Bonfim, Petrópolis-RJ river basin

Soil classes	%	Area (km²)
Litholic Neosols associated with Cambisols, Halliacs and rock outcrops	23%	7,04
Hallic Cambisols associated with Litholic Neosols, Red-Yellow Latosols, Yellow Latosols and rock outcrops	21%	6,33
Red-Yellow Latosols, Yellow Latosols and Halic Cambisols	10%	3,12
Rocky outcrops and urban area	45%	13,74
Total	**100%**	**30,23**

Source: Adapted by Pereira et al., (2021)

The study by Pereira et al., (2021) presents the physical-chemical characterization of soil modal profiles with physical and chemical data of soil horizons of 41 profiles.

For this study, the profile 33 was selected for characterization of the modal profile of the Hapliac Cambisols (Table 2). This soil is the dominant class of soil where the forest and pasture areas occur.

Table 2

Physical characteristics of Profile 33 of Cambissolo Háplico selected in the Bonfim River Basin - Petrópolis-RJ

Class	Textural Class I	Horizon	Deep.	A_T	A_G	A_F	S	Ar	MO	CO	ρ	Ds
			cm	....%...........................							.......g ^{3}......	cm$^-$
Cambissolo Háplico	Franco-Clayey - Sandy	A1	0-20	55	45	10	14	31	3,10	1,80	2,47	1,02
	Franco-Clayey - Sandy	A2	20-42	58	44	14	12	31	2,26	1,31	2,56	1,42
	Clay Sandy	Bi1	42-70	52	39	13	11	37	0,98	0,57	2,57	1,43
	Clay	Bi2	70-96+	41	31	10	13	47	0,97	0,56	**2,65**	**1,34**

A_T = total sand; A_G = coarse sand; A_F = fine sand; S = silt; Ar = clay; MO = organic matter; CO = organic carbon; ρ = particle density and Ds = soil density. Data in bold were estimated
Source: Adapted and supplemented by Pereira et al., (2021)

Horizon (Bi2) at ground depth 70 to 96+ (cm), which did not have particle density (ρ) and soil density (Ds) data, was 2.65g cm-3. For the estimation of Ds, the PTF of Huf dos Reis et al., 2024 (Equation 1) was used.

$$Ds = 1{,}243 + 2{,}983 \times 10^{-3}\,(A_F) + 4{,}187 \times 10^{-3}\,(A_G) - 6{,}208 \times 10^{-2}\,(CO) - 5{,}793 \times 10^{-4}\,(A_r) \text{ .... (1)}$$

Where:

Ds = soil density; A_G = coarse sand; A_F = fine sand; Ar = clay; CO = organic carbon

The hydraulic parameters of ground water retention in the van Genuchten equation (1980), α, n, θ_s e θ_r, were obtained by PTFs Full Model from Medrado & Lima (2014). The TFP proposed by Medrado and Lima (2014) has been used successfully in several studies in Brazil for estimates of the coefficients of the van Genuchten equation (Barros et al., 2021; Costa et al., 2021; Ottoni et al., 2018; Tassinari et al., 2019).

2.3 CURRENT LAND USE AND COVER SYSTEMS PREDOMINANT IN THE BONFIM RIVER BASIN

The original vegetation characteristic of the study area can be divided into forest areas in different stages: primary forests, secondary forests in the early, mid and advanced stages, and the rupestrian vegetation (Kieling, 2014).

The current systems of use and cover of the predominant soil in the Bonfim River basin are the areas of forests and rocky outcrops. The two classes added together account for 77% of the total area of the basin (Table 3). The agricultural areas cover about 7.7% being mainly olive groves. Grassland areas comprise about 3.2% of the area (Table 3).

Table 3

Land Use and Coverage System in the Bonfim Basin, Petropolis-RJ

Uso e ocupação (2006)	Area (km²)	%
Rocky outcrop	10,0	33,1%
Agriculture	2,3	7,7%
Forest	13,2	43,6%
Grassland	1,0	3,2%
Rock vegetation	2,6	8,5%
Urban Area	1,2	3,8%
Total	**30,2**	**100%**

Source: Adaptado de Silva, 2013

2.4 WEATHER DATA

The climate of the Bonfim River basin is characterized by milder summer and drier winter, and the average temperature varies between 13° and 23 °C (Lawall, 2010; Pessoa, 2013).

The municipality of Petrópolis is classified in the Tropical Climate Unit Ameno Úmido Coastal South of Brazil, and has a variation of the annual average potential evapotranspiration of 790 mm to 1158 mm (Fialho & Machado, 2024; Novais & Machado, 2023).

The municipality of Petrópolis has average annual rainfall between 2076 mm and 1208 mm (Nascimento et al., 2021). The average annual rainfall in the high course of the Bonfim basin can exceed 2000 mm and in the low course, 1300 mm up to 900 mm in the driest period (Goulart & Guerra, 1999; Silva, 2013). The time period of the historical meteorological series used in the study was given daily from 01/01/2000 to 31/12/2019.

Rainfall data were obtained initially on the HidroWeb portal after the identification of the rainfall stations in operation in the municipality of Petrópolis. The HidroWeb portal is a platform of the National Water Resources Information System (SNIRH) and provides access to the database containing all information collected by the National Hydrometeorological Network (RHN), through the electronic address (https://www.snirh.gov.br/hidroweb/serieshistoricas) (ANA, 2023). At the same time, a search was carried out on the portals of the National Meteorological Institute (INMET), at the electronic address (INMET: Tempo). The National Center for Monitoring and Alerting Natural Disasters (CEMADEN) (http://www2.cemaden.gov.br/mapainterativo/) and the FTP repository of the State Institute of the Environment (INEA-RJ).

Daily precipitation data were obtained from the rainfall stations listed in Table 4. The "Bonfim" station of the State Institute of the Environment (INEA, 2021) is located within the study area. The "Itamarati" station of the National Agency for Water and Basic Sanitation (ANA, 2022) is located 6.1 km away from the Bonfim station. The station "Pico do Couto" of the National Meteorology Institute (INMET, 2021) is located 20.2 km away from the station Bonfim, all stations are located in the municipality of Petrópolis, as shown in Figure 1.

Table 4

Information concerning rainfall stations with data used in the historical series (2000 to 2019) of the Bonfim - Rio de Janeiro-RJ river basin

Cód. Estação	Name	Responsible	Latitude	Longitude	Altitude (m)
2243327	Bonfim	INEA	-22.4614	-43.0950	1026
A610	Pico do Couto	INMET	-22.4650	-43.2914	1777
2243010	Itamarati	ANA	-22.4853	-43.1492	1085
N/A	N/A	NASA POWER	-22.4614	-43.0950	1026

Source: The authors

The data from the station "Bonfim" INEA, originally available in a time scale of 15 minutes, were accumulated for daily data, to be compatible with those of the stations "Pico do Couto" (INMET) and "Itamarati" (ANA). Soon, they were compiled into spreadsheets that resulted in a historical series with 20 years of flawless daily data. The existing fault filling consisted of comparing the daily rainfall measured in each of the chosen seasons and calculating the arithmetic average of daily rainfall among all the seasons. Precipitation data obtained from

NASA POWER (NASA, 2020) with geographical coordinates of the INEA Bonfim station (Table 4) were also used to fill in faults.

The data on mean air temperature (oC), global solar radiation (W m-2), wind speed (m s-1) and relative air humidity (%), variables necessary for the calculation of potential evapotranspiration (〖ET〗_0) by the Penman-Monteih method (Allen et al., 1998), were obtained at the NASA POWER base (NASA, 2023) based on the geographical coordinates of the rainfall station Bonfim (INEA 2243327). The data are made available free of charge at the e-mail address (https://power.larc.nasa.gov/). These data have been used in the recovery of meteorological data worldwide (Marzouk, 2021; White et al., 2008) and validated with data obtained from surface meteorological stations in Brazil (Monteiro et al., 2018; Rosa et al., 2023). The historical data series used in the ETo calculation comprises the same period (20 years) obtained for precipitation (01/01/2000 - 31/12/2019).

The historical evapotranspiration series of the crop (〖ET〗_c) for grassland and forests were obtained by multiplying the daily data of 〖 〗ET_0 by the culture coefficient (K_c). The established grazing coefficient ranges from K_c= 0,8 - 1,0 (Alencar et al., 2009. Antoniel et al., 2016, Rocha, 2021; Sanches, 2018; Sanches et al., 2019). In this work, for the pastures, K_c= 0.70 was adopted, due to the degradation of the pastures in many of the areas.

In primary tropical forests, the value of K_c= 1.00 was used (Muniz, 2017; Villa Nova et al., 1976), and this is the value used in this study. ETc data was partitioned into evaporation and perspiration. For pasture he used the values of 25% for evaporation and 75% for transpiration. The relatively high percentage for evaporation was due to the knowledge of degraded pastures in the region, verified by site visits. For forest area it was considered that 10% of 〖ET〗_c had the potential to be lost by evaporation and 90% by transpiration. The partition of the 10% value for direct soil evaporation in forest areas is due to the fragmentation of forest areas in this basin and large occurrence of interspersed rock outcrops in forest areas.

2.5 HYDRUS-1D SIMULATION

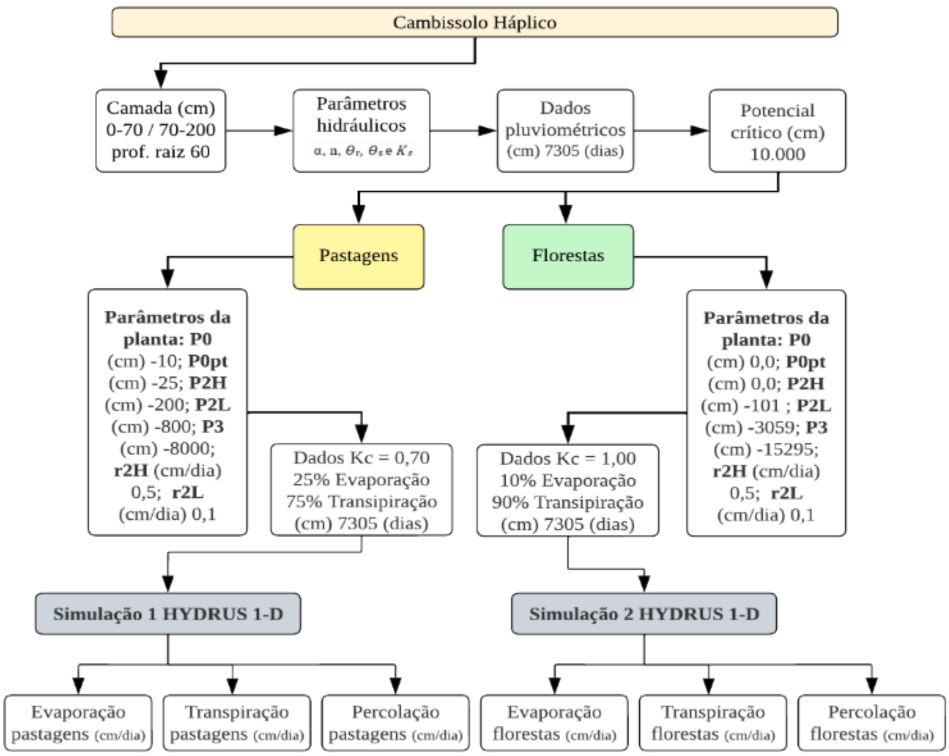
The program HYDRUS-1D, version 4.17.01.40 (Šimůnek et al., 2008) was used. Two direct simulations were carried out, for the Cambisol Haplius under pastures and forests. Variable Upper Boundary Condition consisted of daily weather data (7,305 days) of precipitation, evaporation, and sweating, all with unit of (cm/day). It was admitting up to 10 cm of water depopulation on the surface. For Lower Boundary Condition, Free Drainage was chosen because the water table was well below the lower limit of the profile studied. The water content in the field capacity (10 kPa) was considered for initial soil conditions. A depth of 200 cm was adopted, and this was simplified with only two layers. Being the first layer with thickness between 0-70 cm and second of 71-200 cm, with retention distinct hydraulic properties, estimated via PTF Medrado & Lima (2014) for the parameters of van Genuchten (1980), considering the coefficient m = 1 - 1/n.

The data of saturated hydraulic conductivity Ks were estimated by the Splintex 2.0 model (Silva et al., 2020) and, tortuosity factor of the soil, was adopted the value I=0.5, value suggested by Mualem (1976).

Simulation under pastures differs from simulation under forest, mainly in relation to the parameters of water absorption by the roots (parameters of root absorption of water by the Feddes model) and the partitioning of meteorological data of potential evapotranspiration in evaporation and transpiration of pastures and forests (Figure 2). The length of the root system was considered 60 cm for both systems of use.

Figure 2

Flowchart of simulations considering different soil covers, grasslands and forests in HYDRUS-1D



Source: The authors

ETo's calculations were estimated by the Penman-Monteith equation (FAO, 56) (Allen et al., 1998) as detailed above, with ETo data multiplied by the Kc of the cultures and divided into Evaporation and Transpiration.

For the simulation on pastures, the calculation of the evapotranspiration of the crop (〖ET〗 _c) of pastures and for forest was adopted, the calculation of the 〖 〗ET_c of forests. The roots were adopted at a depth of 60 cm and their distribution was considered evenly distributed.

The Feddes model that parametrizes the capacity of crops to absorb water according to the availability and potential of water in the soil (Feddes et al., 1978), was parametrized for pasture, with data available in the forest program with values used by Muniz, 2017. Feddes values are shown in Figure 2.

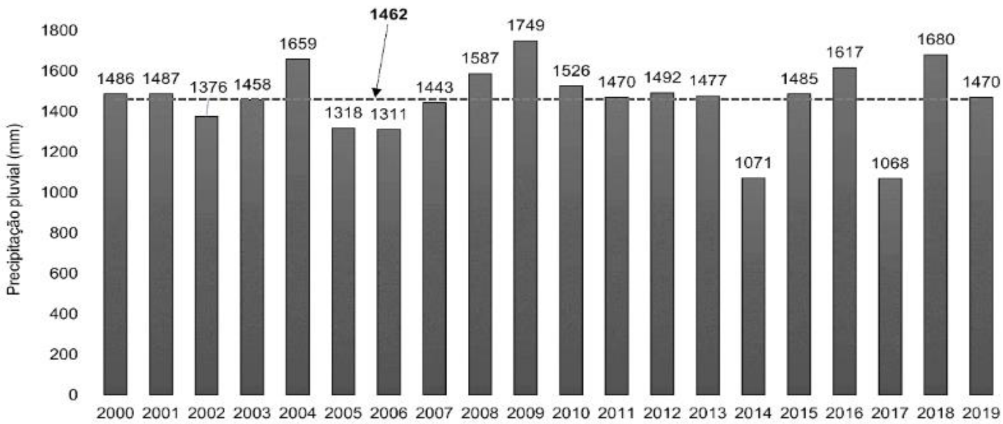
3 RESULTS AND DISCUSSION

3.1 RAINFALL AND POTENTIAL EVAPOTRANSPIRATION (ETO)

The total rainfall accumulated in the Bonfim basin in Petrópolis-RJ, over the years 2000 to 2019 was 29231 mm, with an annual average of 1462 mm. The year that rained the most was 2009 with 1749 mm and the driest year was 2017 with 1068 mm (Figure 3).

Figure 3

Rainfall during the years 2000 to 2019 in the Bonfim river basin, Petrópolis-RJ



Source: INMET, ANA and INEA, NASAPOWER data organized by the authors

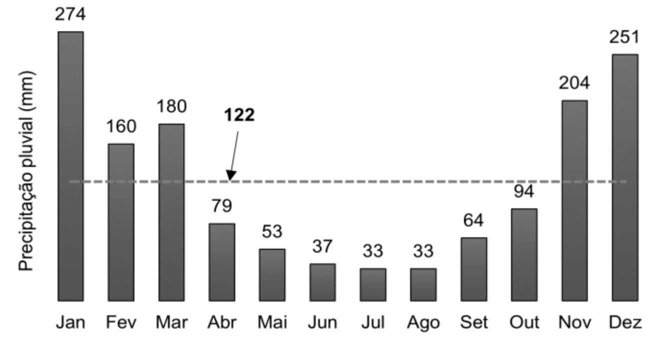
The driest months (April to September) over the years 2000 to 2019, present an average of 298 mm of rainfall, equivalent to 20% of the average annual precipitation, and the wettest months (October to March) an average of 1163 mm, equivalent to 80% of the average annual rainfall (Figure 4), corroborating the values found in the mountainous region of Rio de Janeiro and the Bonfim region (André et al., 2008, Lawall, 2018).

André et al. (2008) corroborate the distribution of rainfall in the rainiest and driest months found in Bonfim. According to the author, the Serrana region presents 1330 mm of average precipitation, and in the wettest months (October to March), 79% of the average annual precipitation (1056 mm) and in the driest months a total of 274 mm (21%) of the average annual precipitation.

According to Lawall (2018) the average rainfall from 2009 to 2012 for the driest months (April to September) was 294.5 mm and the wet months (October to March) was 975.75 mm, according to rainfall data observed in Sítio das Nascentes season, located in the Bonfim region, similar results were found in the present study.

Figure 4

Average monthly rainfall during the years 2000 to 2019 in the water catchment area of the river Bonfim, Petrópolis-RJ

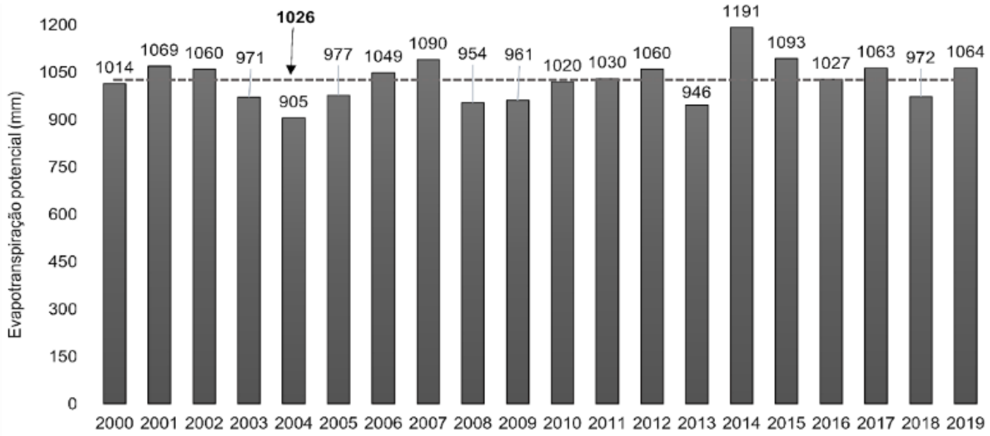


Source: The authors

The municipality of Petrópolis has an annual average ETo of 790 mm to 1158 mm second, Fialho & Machado (2024) and Novais & Machado (2023). These values are in agreement with the values found in this study. The water potential that could be evapotranspirated (ETo) over the years 2000 to 2019 was estimated at 20518 mm, with an annual average of 1026 mm. The year with the largest ETo was 2014 with 1191 mm, however this year presented rainfall below the average of the period, totaling 1071 mm. The year with the smallest ETo was 2004 with 905 mm (Figure 5), and the precipitation in 2004 was 1659 mm, above the annual average in mm (Figure 3).

Figure 5

Potential evapotranspiration (ETo) during the years 2000 to 2019 in the catchment area of the river Bonfim, Petrópolis-RJ

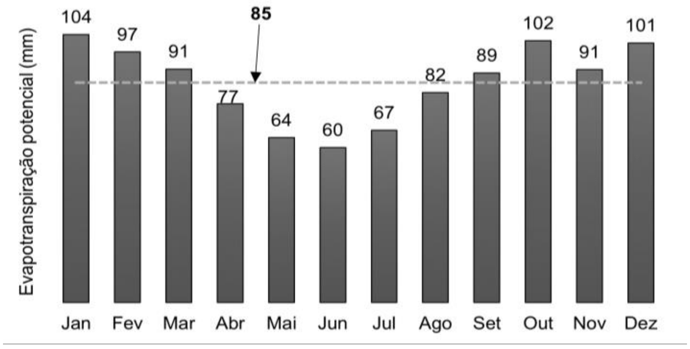


Source: The authors

The driest months (April to September) over the years 2000 to 2019, have on average 441 mm ETo, equivalent to 43% of the annual mean ETo (1026 mm), and the wettest months (October to March) have 585 mm, equivalent to 57% of the annual mean ETo. The monthly mean evapotranspiration was 85 mm (Figure 6). ETo volumes in the dry season exceed total rainfall volumes by 47%. In the rainy season the total volumes of rainfall are 50% greater than the quantities of ETo. It should be noted that ETo is a volume of water with the potential to return to the atmosphere by evaporation and or transpiration, the estimated volumes of evaporated and transpired water will be presented below.

Figure 6

Monthly average evapotranspiration during the years 2000 to 2019 in the catchment area of the river Bonfim, Petrópolis-RJ



Source: The author

3.2 PARAMETERIZATION OF SOIL HYDRAULIC PROPERTIES

The coefficients of van Genuchten's equation (1980), α, n, θ_(s) and θ_r, for the Cambisol and the two-layer quadruple, were estimated with the PTF of Medrado & Lima (2014) and are presented in Table 5. The predictor parameters used in TFP were obtained from the characterization of a profile of Cambisol's Quadruple, presented in Table 2.

Table 5

Parameters of the van Genuchten equation estimated via PTF Medrado and Lima (2014) for a Cambisol - Bacia do Bonfim - RJ

Layer	Θ_s	Θ_r	α	n	I	K_s
1 - 0-70	0,513	0,183	0,536	1,588	0,5	133,220
2 - 71-200	0,324	0,132	0,603	1,262	0,5	57,846

Θ_s e Θ_r, are the residual humidity at saturation (cm3 cm-3); α and n are empirical parameters, dimensionless; Ks, is the saturated hydraulic conductivity of the soil (cm day-1); I is a tortuosity factor of the soil, value suggested by Mualem (1976) using the value of 0.5.
Source: The authors

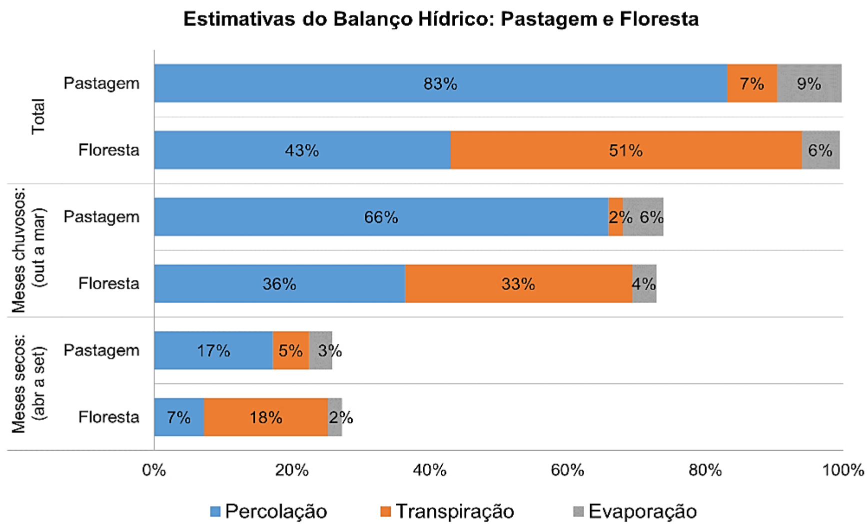
3.3 ESTIMATES OF WATER BALANCE COMPONENTS IN SOIL - PASTURES AND FORESTS

The average volumes (in mm) of the components of the water balance for the whole period were 107 mm of sweating (7% of the average annual precipitation), 136 mm of evaporation (9%), making a total of 243 mm and percolation totals 1215 mm corresponding to 83%, in the area under pasture (Figure 7). The BH in the area under pasture, considering the average rainfall (1462 mm), showed that in the rainiest months (October to March) the perspiration was 30 mm (2%), evaporation was 87 mm (6%) and percolation was 964 mm (66% of the average rainfall). In the driest months (April to September), sweating was 77 mm (5%) and evaporated volume was 49 mm (3%) and percolated volume was 251 mm (17%).

The BH in the area under forest, in the rainiest months (October to March) indicated a volume of 482 mm transpirated (33%) and 51 mm evaporated (4%) and the percolation totaled 532 mm (36%). In the driest months (April to September), in the areas under forest, the average volume of water transpiration was 263 mm (18%), evaporation presented a volume of 30 mm (2%) and percolation totals a volume of 105 mm (7%). In the forest areas the total percolation, transpiration and evaporation in relation to the average rainfall were 637 mm (43%), 745 mm (51%) and 81 mm (6%), respectively (Figure 7).

Figure 7

Percentage of percolated, perspirated and evaporated volumes of water in relation to rainfall to the Cambissolo Háplico under pastures and forests in the basin of the river Bonfim, Petrópolis-RJ



Source: The authors

The uncertainty in the balance of water mass was 0.045% for the simulation with cover of the ground under pasture and 0.10% under forest, according to the results obtained in HYDRUS-1D. As the variation in soil water storage at the initial and final time was not taken into account in the balance, probably a part of this value refers to the variation of water stored in the soil. In the present study, surface runoff was not calculated due to the use of daily data in the simulation, the process of generating and estimating runoff water volumes requires hourly data or better temporal resolution when estimating it in HYDRUS-1D.

Casagrande et al. (2021) developed a model, Soil-Vegetation-Water (SOVEWA) and together with two other simulation programs, the Global Land Evaporation Amsterdam Model (GLEAM), and HYDRUS 1-D calculated the main components of the water balance to evaluate the use of soil cover, under pastures and under forests in the Amazon. According to these authors, the transpiration of the forest totals about 50% of the total precipitated, with values close to those in the models used. The authors concluded that forests have higher rates of transpiration and interception than grassland, and that evaporation rates were higher in grassland. In this work, the results corroborate these values, since the percentages of transpiration in the forest were 51% and in the pasture 7% of the precipitated volume. The percentage of evaporation was 9% in the pasture and 6% in the forest (Figure 7).

According to Guauque-Mellado et al. (2022), studying a Red Latosol in the Atlantic Rain Forest, the characteristics of the soil of infiltrating, retaining and making available water are fundamental for maintaining the levels of evapotranspiration during periods of drought, in particular in periods of severe drought.

The reduction in the percentage of evapotranspirated water from the rainiest months to the driest months in the forest area was 82%, going from average values of 553 mm to 293 mm.

During the driest months, the percentages of evaporation and transpiration for grazing were 5% transpiration and 3% evaporation, and for forest areas 18% and 2%, respectively. Hodnett et al. (1995) showed that the variability of water storage in the soil was considerably greater under pasture than under forest, especially after rainfall events in the dry season. In this study, the results corroborate those found by the authors, since, in the driest months, the percolation in the pasture was 251 mm (17%) and in the forest 105 mm (7%), in the rainiest, the percolation in the pasture was 964 mm (66%) and in the forest 532 mm (36%).

Increased underground recharge (percolation) after forest deforestation will only succeed if the soil's hydraulic properties remain unchanged after deforestation, but in cases of mechanical deforestation of forests and conversion to grassland, most often lead to severe compaction and degradation of the soil surface (Hodnett et al., 1995). According to the author, deforestation in a forested area ends up reducing the levels of infiltration, generating an increase in surface runoff and consequently erosion, and with this, an increase in the risks of flooding. When analyzing forest-to-pasture conversion scenarios, it should be considered that evaporation and perspiration rates in the forest are higher during dry seasons. During the rainiest months, the highest volume of percolation occurs in the pasture and the highest rates of evaporation and transpiration in the forest. Reduced evapotranspiration in grassland may lead to reduced water returned to the atmosphere in the form of vapor, which may directly influence water availability. Whereas forests, with higher rates of evapotranspiration, have the opposite effect on water availability. Considering that forests play an important role in the hydrological cycle, as they directly interfere with the redistribution of rainfall (Carvalho-Santos et al., 2016), it is not recommended to convert forests to grassland in watersheds of Cambissolo Háplico soil. The benefits in maintaining the forested area are greater than converting them into pasture, since forests have a high ecosystem capacity for preserving water resources and regulating the climate.

The alterations that intervene in the water balance must be taken into consideration when planning programs for changes in the use of the land and the conservation of natural resources, in river basins.

4 CONCLUSIONS

The average annual rainfall was 1462 mm, with the driest year (2017) being 1068 mm and the wettest year (2009) being 1749 mm. During the rainy months (October to March), 80% of the annual precipitation occurs.

The mean potential evapotranspiration was 1026 mm. With a minimum value of 905 mm in 2004 and a maximum value of 1191 in 2014.

The water balance showed that for the pasture areas 83% of the volume precipitated percola, 7% transpirated and 9% evaporated.

The water balance showed for the forest areas 43% of the volume precipitated by percola, 51% transpirated and 6% evaporated.

The percentages of evapotranspirated precipitation in the pasture and forest areas in the driest months were 8% and 20%, respectively. In the rainiest months, the percentages are 8% in pasture and 37% in forest areas.

The percentages of percolated rainfall in the dry season were 17% in the pasture area and 7% in the forest areas. In the rainy season these percentages are 66% and 36%, respectively.

It is recommended to calibrate and validate the model using data measured in the Bonfim watershed, Petrópolis-RJ, with monitoring of water dynamics in the different land use systems and/or monitoring of percolated water.

It is suggested to apply this modeling methodology to other soils of the basin and other land use systems to have in the future a mosaic of the different land use systems in the different soil classes and the impacts of these changes on the flows of water balance components.

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