Estimating Water Loss in an Environmental Protection Area - Minas Gerais, Southeast Brazil

Estimativa de perda de Água em uma Área de Proteção Ambiental - Minas Gerais, Sudeste do Brasil

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Abstract

Evapotranspiration is an essential component of the water budget, and ETR dynamics can change the hydrological regime of an area. Our objective was to analyse the behaviour of ETR in classes of land use in the domain of the Cerrado Biome during winter and summer. The study area involves an environmental preservation area (Rio Pandeiros). We used the SEBAL algorithm (Surface Energy Balance Algorithm for Land) and Landsat-8 satellite image to estimate the ETR. We selected eight classes of land use (Woodland Cerradão, Wooded Cerrado, Dry Forests, fire-degraded Cerrado, central pivot irrigation, pasture, eucalyptus, Palm Swamp Veredas). We apply principal component analysis (PCA) by land use, considering the variables: ETR, leaf area index, sensitive heat flow, latent heat flow, aerodynamic resistance, radiation balance, and elevation. The climatic period influences the phenological stage of the plant, and consequently, there are changes in the ETR rates. In the study area, there is a predominance of Wooded Cerrado, which has a low ETR (2.5 mm d^{-1} in summer and 1.1 d^{-1} in winter). Still, the conversion to anthropic uses generates an increase in this variable. In summer, all classes of land use have higher ETR, but the highest rates occur in eucalyptus forests and swamps (Veredas) (~7.0 mm d^{-1}). Therefore, the indiscriminate growth in forms of land use with high ETR, for example, eucalyptus forests, can negatively affect the water regime of the study area.

Keywords: Evapotranspiration; SEBAL; Remote Sensing; Spatial variability; Land Use.

Resumo

A evapotranspiração (ETR) é um componente do balanço hídrico, e a dinâmica de ETR pode alterar o regime hidrológico de uma região. Nosso objetivo foi analisar o comportamento da ETR nas classes de uso da terra no domínio do bioma Cerrado durante o inverno e o verão. A área de estudo envolve uma Área de Preservação Ambiental (APA - Rio Pandeiros). Utilizamos o algoritmo SEBAL

(Algoritmo de Balanço de Energia de Superfície para Terra) e a imagem de satélite Landsat-8 para estimar o ETR. Selecionamos oito classes de uso da terra (Cerradão, Cerrado ralo, Mata Seca, Cerrado degradado pelo fogo, irrigação por pivô central, pastagem, eucalipto e Veredas). Aplicamos a análise de componentes principais (ACP) por classes de uso da terra, considerando as variáveis: ETR, índice de área foliar, fluxo de calor sensível, fluxo de calor latente, resistência aerodinâmica, balanço de radiação e altitude. O período climático influência o estágio fenológico da planta, consequentemente, há mudanças nas taxas de ETR. Na área de estudo, predomina o Cerrado ralo, que apresenta baixa ETR (2,5 mm d^{-1} no verão e 1,1 d^{-1} no inverno). A conversão para usos antrópicos gera um aumento na ETR. No verão, todas as classes de uso da terra apresentam maior ETR, mas as taxas mais altas ocorrem nas áreas de eucaliptos e Veredas (~7,0 mm d-1). O crescimento indiscriminado nas formas de uso da terra antrópicos com alta ETR, por exemplo, florestas de eucalipto, pode afetar negativamente o regime hídrico da área de estudo.

Palavras–chave: Evapotranspiração; SEBAL; Sensoriamento Remoto; Variabilidade espacial; Uso da Terra.

1. INTRODUCTION

The Brazilian territory naturally has a poor distribution of water resources; most of the water is in the Amazon rainforest (~80%) (CAPELLARI; CAPELLARI, 2018). There are also environmental problems that affect the water system, for example, deforestation, degradation of pastures, and the concentration of irrigation projects in areas of low potential (Oliveira *et al.*, 2014; HUNKE *et al.*, 2015) These changes in land use influence the behaviour of evapotranspiration rates (ETR) (LI *et al.*, 2017; SHANMUNGAN *et al.*, 2020), which is a significant component of the energy and water balance of terrestrial ecosystems (ALLEN *et al.*, 2011a). Therefore, recognising the dynamics of ETR and other environmental variables related to water resources is essential for land use planning.

Although the tropical climate predominates in Brazil, there are regions of higher rainfall, but there are occasional problems of water scarcity (TARGA; BATISTA, 2015). Factors vary between anomalous climatic periods of low rain and anthropic influence (NAZARENO; LAURANCE, 2015; OTTO *et al.*, 2015). The consequences of water scarcity are even higher in dry climate regions, and there is a portion of southeastern Brazil that has this condition (Norte de Minas). Another aspect is the population growth of the cities (BOLAY, 2020), and a continuous increase in agricultural areas. These factors generate pressure on ecosystems, especially the Cerrado Biome (SANO *et al.*, 2008).

The Brazilian Cerrado is the second largest Biome, and this region has river springs from important Brazilian hydrographic basins and has several aquifer recharge areas (CALLISTO *et al.*, 2016). However, the Biome is strongly affected by land-use changes (KLINK; MACHADO, 2005), and this aspect most significantly affects the hydrological regime of a region (VÖRÖSMARTY *et al.*, 2000). Evapotranspiration rates are responses to these changes; study considering the ETR variable, showed that conversion of native forests could cause a reduction in ETR (FAUSTO *et al.*, 2016; CAIONI *et al.*, 2020), or even increase ETR with the use of eucalyptus forests mainly during the initial growing (GONÇALVES *et al.*, 2017).

Among the forms of land use in the Cerrado, eucalyptus forests have been increasing considerably (MAQUÈRE *et al.*, 2008). However, some studies show that reforestation negatively influences the amount of water in watersheds small (TATSCH, 2006; LIU *et al.*, 2016). On the other hand, the growth of forested areas increases the transport of steam to the atmosphere, positively affecting the hydrological regime on a regional scale (LIU *et al.*, 2016). Therefore, reforestation must concentrate on the areas with the highest water potential, to prevent areas of water scarcity from being affected by the ETR elevation (LIU *et al.*, 2016).

The challenge with ETR studies is the measurement for large areas, and conventional methods despite being more accurate have a local response (TANAKA *et al.*, 2016; ARAÚJO *et al.*, 2017). Alternatively, remote sensing allows obtaining ETR data in large areas (BEZERRA *et al.*, 2008; BEZERRA *et al.*, 2014), using algorithms, such as SEBAL (Surface Energy Balance Algorithm for Land) (BASTIANSSEN, 1995). Therefore, studies with remote sensing algorithms allow identifying the relationship between ETR and solar radiation (VALIPOUR, 2015), landscape (COWLEY *et al.*, 2017), soils (HAGHIGHI; KIRCHNER, 2017), and land use (LI *et al.*, 2017; ANDRADE *et al.*, 2020; IVO *et al.*, 2020). Despite the potential of the algorithm, most studies focus on a few classes of land use.

Our objective was to analyse the seasonal behaviour of the ETR and the relationship with other atmospheric variables in the context of different Cerrado vegetation types, crops, and anthropised areas.

2. MATERIAL AND METHODS

2.1. Study Area

The study area is a Protected Area (PA), called the Rio Pandeiros Environmental Preservation Area (RP-EPA). Located between the coordinates -15º 02' 50" and -15º 43 '38" south latitude and -45º 17' 26" and -44º 37' 29" longitude west of Greenwich (**Erro! Fonte de referência não encontrada.**). The RP-EPA covers the municipalities of Januária, Bonito de Minas, and Cônego Marinho. The selected samples for the study was: Woodland Cerradão, Wooded Cerrado, Dry Forests, Palm Swamp Veredas, eucalyptus, pasture and fire-degraded Cerrado. The climate varies from Sub-humid Tropical, with proximity to the Sub-Humid limit, with periods of concentrated rain between October to March (LEITE *et al.*, 2018a). The annual precipitation is around 1057.4 mm (SANTOS *et al.*, 2020).

The regional geomorphology is of flattened surfaces, shallow valleys, and isolated residual hills. These are typical geomorphological features of the São Francisco depression (Santos *et al.*, 2020). Hypsometry ranges from 449 to 846 m, with higher areas to the north. The topography is a determining factor in the spatial distribution of land uses, especially when considering anthropic uses, since eucalyptus forests are on the Plateaus, in the northeast portion. The soils in the region are sandy, acidic, and have low fertility. In the areas upstream of the Pandeiros River basin, Typic Quasrtzmpsament occurs (ALMEIDA, 2016). In the downstream areas, the soils are more humid, mainly in Palm Swamp Veredas.

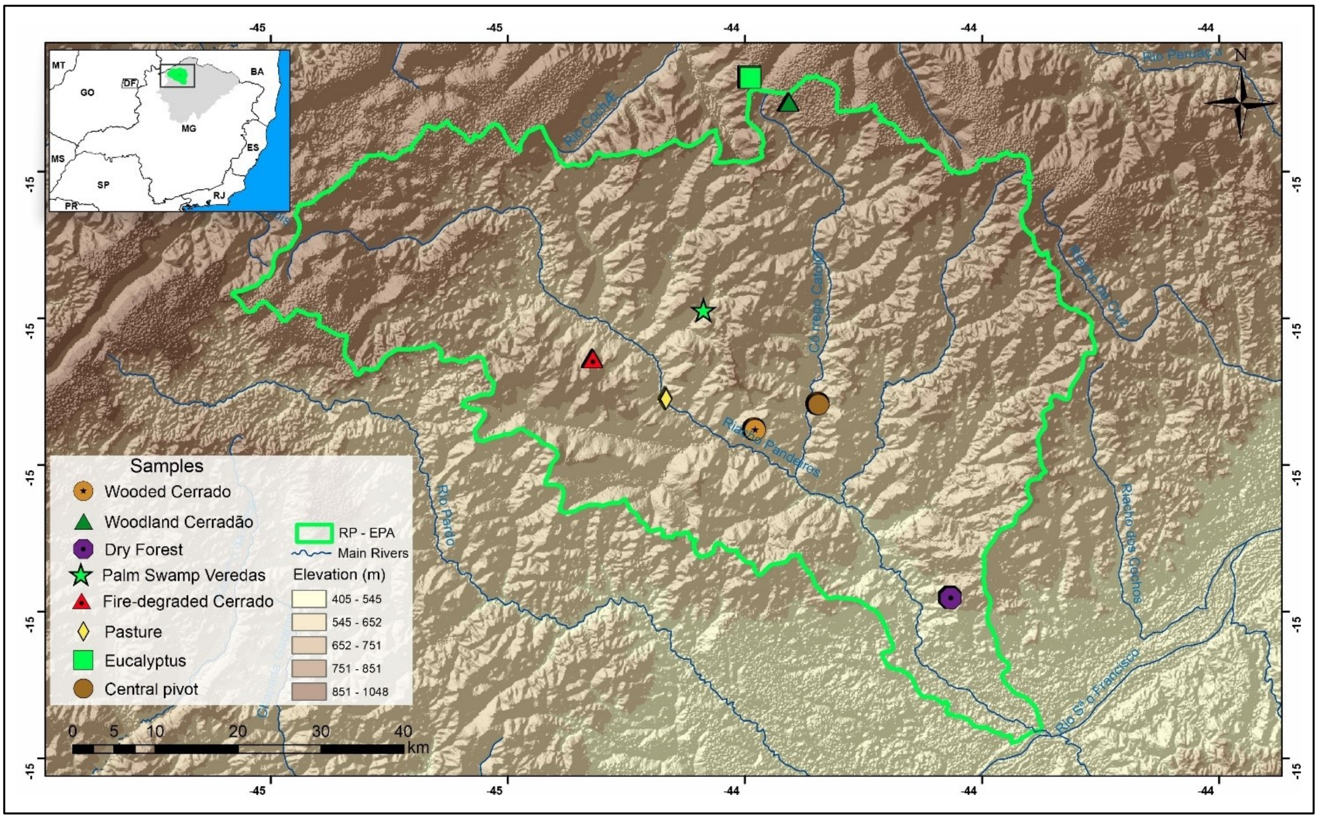

Figure 1 - Location map of the Rio Pandeiros Environmental Protection Area (EPA-RP), with sample points of land use classes.

2.2. Evapotranspiration Modelling

We used images from the OLI and TIRS sensors of the Landsat-8 satellite, referring to the following dates: 07/13/2018 and 01/21/2019 orbit and point 219/071. From the database of USGS (USGS, 2020). We used the model maker of the Erdas software to estimate the ETR. This model allows the entry of the images as well as the parameters of the moment of acquisition of the images, for example, angle of elevation of the sun, distance Earth-Sun, additive (Gain) and multiplicative (offset) factors of rescheduling for radiance and reflectance. These parameters are essential and feed the SEBAL algorithm, with some data, for example, global solar radiation, wind speed, and air temperature.

We convert the digital levels of satellite images into radiance. From the radiance, it was possible to obtain reflectance, this in conjunction with the multiplicative and additive factors (Alves *et al.*, 2017). The reflectance data allow us to calculate the surface albedo, vegetation indices (Normalized Difference Vegetation Index NDVI, Soil-adjusted vegetation index SAVI and Leaf Area Index LAI), thermal and longwave emissivity. Thermal emissivity is an input parameter to generate the surface temperature. Longwave emissivity allows the calculation of longwave radiation emitted by the surface (ALVES *et al.*, 2017).

With the parameters from the previous step, it is possible to calculate the radiation balance (Rn) (Equation 1), which represents the energy available for biophysical processes at the surface-atmosphere interface (BIUDES *et al.*, 2014). After obtaining the Rn, we calculate the heat flow in the soil (G) (Equation 2). The heat flow in the soil represents the part of the energy responsible for the vertical heating of the soil.

$$Rn = Rs\downarrow - \alpha Rs\downarrow + RL\downarrow - RL\uparrow - (1-\epsilon)RL\downarrow$$ **(Equation 1)**

Where: $Rs\downarrow$ is the global solar radiation (automatic station of Januária / MG), α is the surface albedo, $RL\downarrow$ and $RL\uparrow$ are incidents and emitted longwave radiation, respectively (Allen *et al.*, 2011b), Є is the longwave emissivity.

$$G/Rn = [(\frac{Ts}{a})(0{,}0038a + 0{,}0074a^2)(1 - 0{,}98NDVI^4)$$ **(Equation 2)**

Where Ts is the surface temperature, and NDVI is the vegetation index by the normalised difference.

In sequence, we calculate the flow of sensitive heat (H) (Equation 3). The process to obtain the sensitive heat flow, as well as the atmospheric stability corrections with the length of Monin Ubukov, depends on iterations (repetition of calculations) described in Bastianssen *et al.*, (1998). From the data of Rn, G, and H, it was necessary to measure the latent heat flow (LE) (Equation 4).

$$H = p.Cp.dT/Rah$$ **(Equation 3)**

Where p is the specific humidity of the air (1.15 $kg.m^{-3}$), cp is the specific heat of the air, dT is the temperature difference between the surface and the air, and Rah is the aerodynamic resistance of the air to the transport of heat.

$$LE = Rn - G - H$$ **(Equation 4)**

The LE represents the energy available for converting water into liquid water vapour (SANTOS *et al.*, 2010). With these parameters, the evaporative fraction (EF) (equation 5), which represents daytime evapotranspiration, is obtained. In the end, we calculate the actual daily evapotranspiration by extrapolating the values of the EF (equation 6) (VELOSO *et al.*, 2017).

$$EF = LE/(Rn - G) \quad \textbf{(Equation 5)}$$

$$ETR = 86400\ \frac{FE.Rn24h}{n} \quad \textbf{(Equation 6)}$$

Where: Rn24 represents the daily radiation balance, and n is the latent heat of vaporisation.

2.3. Statistical Analysis

In a computational environment, we selected sample areas by the class of land use (Woodland Cerradão, Wooded Cerrado, Dry Forests, fire-degraded Cerrado, central pivot irrigation, pasture, eucalyptus, Veredas Palm Swamp). We extracted the variable values of remote sensing (leaf area index LAI; real evapotranspiration ETR; sensitive heat flow H; latent heat flow LE; aerodynamic resistance Rah; radiation balance Rn; elevation) for a grid of 80 points per class. The source of most of these variables is the SEBAL algorithm. The altimetry was from SRTM image 30x30 m (USGS, 2020). The altitude parameter is important because it influences the dynamics of air circulation, a determining factor for evapotranspiration.

For each land use, we elaborated a box-plot to observe the variation of ETR in the summer and winter periods. In all variables, we apply Principal Component Analysis (PCA) to analyse relationships. We use the R software (RCORE TEAM, 2016).

3. RESULTS AND DISCUSSION

3.1. Spatial Distribution of Evapotranspiration

In RP-EPA, evapotranspiration rates showed variability by classes of land use and by climatic period (**Erro! Fonte de referência não encontrada.**). The average ETR in winter was 2.48 mm d^{-1} and in summer 5.14 mm d^{-1}, representing a 51.75% increase. In general, the highest values, ranging from 2.93 to 4.28 mm d^{-1} in winter, and 6.24 to 8 mm d^{-1} in summer, are in areas southwest of the RP-EPA. In winter, 64.7% of the values ranging between 2 to 2.94 mm d^{-1}. While in summer, the highest concentration (57.78%) of the values is between 4.01 to 6.24 mm d^{-1}. Several studies also demonstrate this seasonal behaviour of ETR (SANCHES *et al.*, 2011; VELOSO *et al.*, 2020).

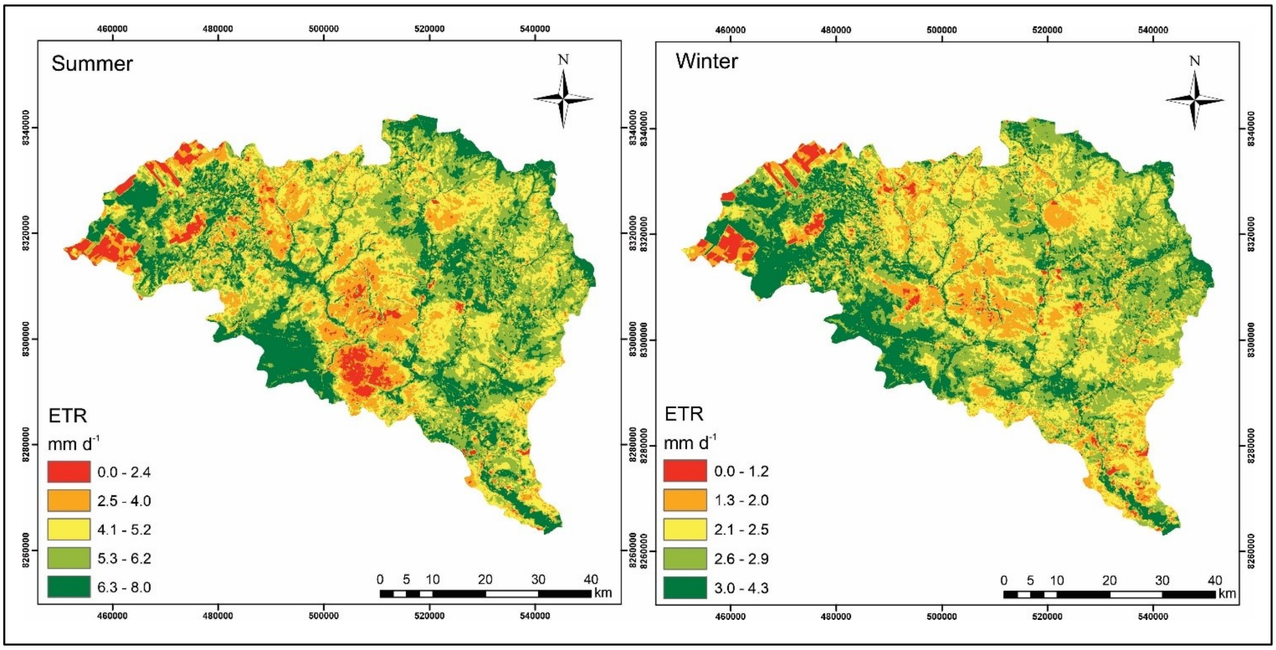

Figure 2 - Spatial Distribution of ETR (Summer and Winter) for EPA-RP.

In the northeast region, in plateau areas, the ETR values are high. The relief should influence this aspect, as they are areas where the wind easily removes moisture from the air near the vegetation (MCVICAR *et al.*, 2008). In the regions of Riparian Forest and Palm Swamps Veredas, there are also high ETR (2.52 to 4.35 mm d^{-1} in winter, and 5.41 to 8 mm d^{-1} in summer), which accompany the drainage line, a fact evident in the central portion of the RP-EPA. ETR values in these areas range from 2.52 to 4.35 mm d^{-1} in winter, and 5.41 to 8 mm d^{-1} in summer. In the northwest, it has a concentration of land (bare soil) designated for crops, which showed the lowest values in both periods, with 1.2 to 1.99 mm d-1 winter and 2.38 mm d^{-1} summer.

In the downstream portion of the Pandeiros River, there is an extensive humid area, forming a vast swamp, the only one in the state of Minas Gerais (SANTOS *et al.*, 2020). As it is a constantly humid area, the ETR values are high, and there is no significant variation in the periods (with 2.93 to 4.28 mm d^{-1} in winter and 6.24 to 8 mm d^{-1} in summer).

3.2. Evapotranspiration by Land use Classes

In general, the average values of ETR by the class of land use vary according to climatic seasonality (**Erro! Fonte de referência não encontrada.**). Phytophysiognomies with larger tree size and a more formed canopy influence the higher rates of ETR in the summer, as the change in the structure of the canopy systematically affects the resistance to heat diffusion and promotes increased vapour transfer (VELOSO *et al.*, 2020). For example, the Dry Forest vegetation increases the ETR in the summer period, and this period corresponds to the leaf restoration (SANTANA *et al.*, 2010).

In the areas of Palm Swamps Veredas, although it has a low leaf structure, the ETR was high. This behaviour is due to soil moisture, and as they are open systems, the wind circulation favours the increase in ETR (SOMAVILLA; GRACIANO-RIBEIRO, 2011). On the other hand, in fire-degraded Cerrado, where the leaf structure is absent, the high ETR (in summer). This behaviour is due to the release of nutrients from the soil by mineralisation. In the context of the Cerrado, the highest level of nutrients and biomass are in underground portions (CASTRO; KAUFFMAN, 1998). Therefore, during the rainy season, the vegetation grows very fast, contributing to an increase in ETR.

Pastures varied according to seasonality, with higher values in summer and lower in winter, according to a previous study by Leite-Filho *et al.*, (2020). Wooded Cerrado showed the same behaviour as the pastures, with low ETR variation between periods. In the central pivot irrigation areas, there is a wide variation of ETR. The planting season must be the main factor for this variation, including the technique of handling with irrigation. These factors combined tend to increase the ETR (SUYKER; VERMA, 2009).

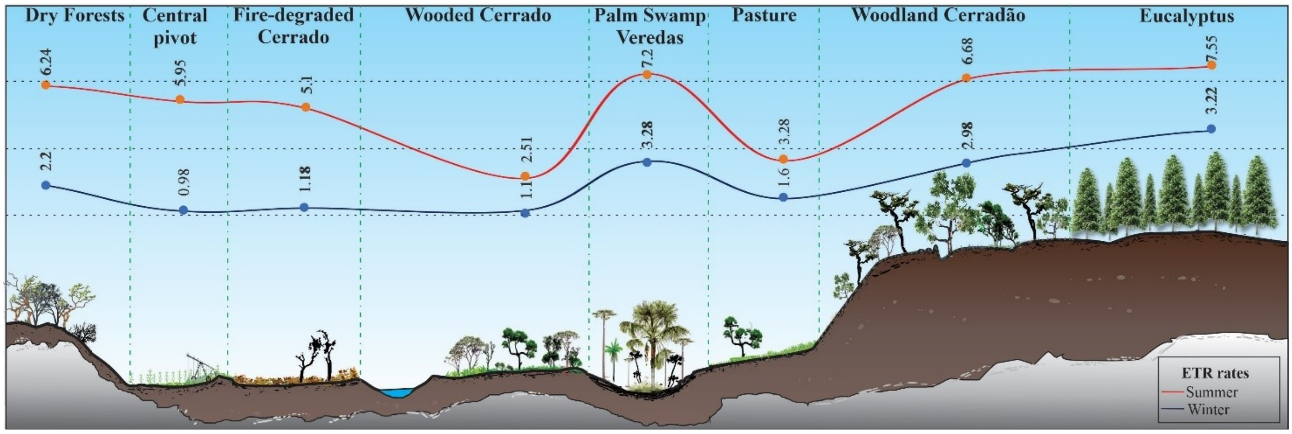

Figure 3 - Representative scheme of land use classes and behaviour of evapotranspiration rates.

We analyse variations in ETR rates for each land use (Figure 4). We considered four phytophysiognomies in the Cerrado, including the anthropised areas (Woodland Cerradão, Wooded Cerrado, Dry Forests, and fire-degraded Cerrado). The Palms Swamps Veredas, being a wetland, is discussed separately.

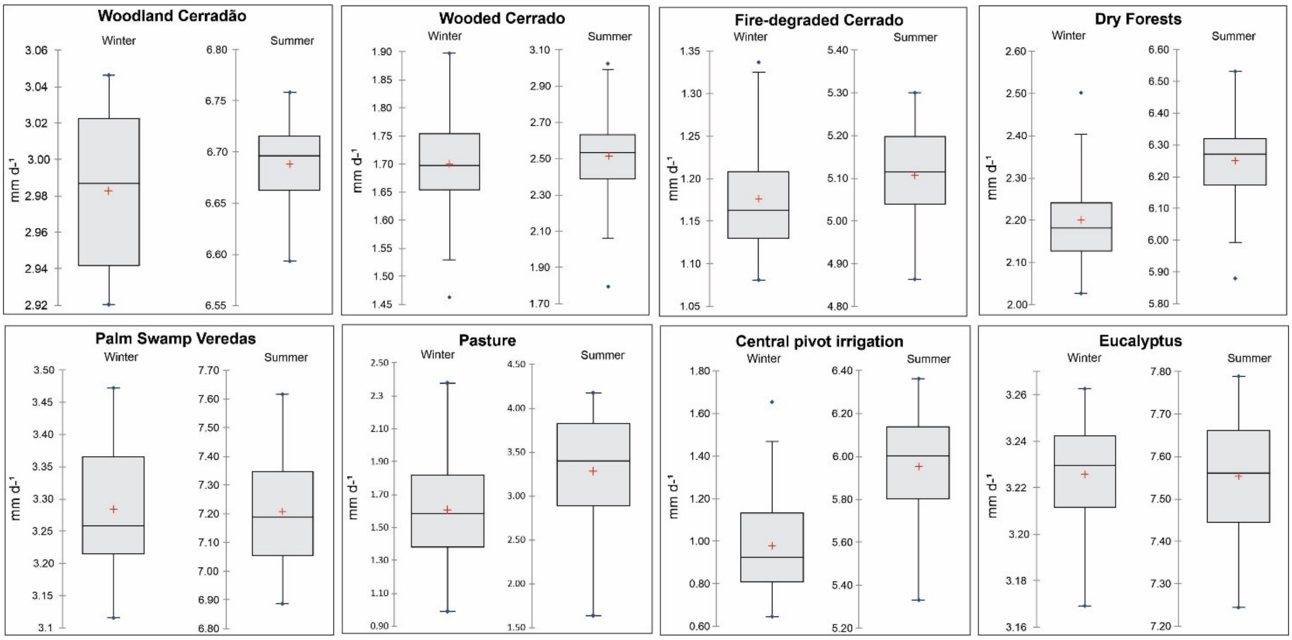

Figure 4 - Box-plot with Mean, median, 1st, and third quartile, outliers close, maximum and minimum values, for ETR rates by land use classes in summer and winter.

3.2.1. Cerrado

In Woodland Cerradão the average ETR was 2.98 mm d^{-1} in winter, and 6.68 mm d^{-1} in summer. The values are in the ETR range of other studies (GIAMBELLUCA *et al.*, 2009; MARTINS; ROSA, 2019). However, between periods there is a wide variation in water consumption due to climatic seasonality, as in summer, the minimum ETR is approximately twice (55.69%) the maximum ETR in winter.

In Wooded Cerrado, the average ETR for the winter was 1.70 mm d^{-1}, with a distribution ranging from 1.65 to 1.75 mm d^{-1}, and for the summer, the average value was 2.51 mm d^{-1} and concentration between 2.39 to 2.63 mm d^{-1}. In the Wooded Cerrado, the rarefied vegetation due to edaphic soil factors also provides lower ETR (MOREIRA *et al.*, 2010). Another factor to consider is the loss of biomass in winter, which causes a decrease in the transpiration of vegetation (BEZERRA *et al.*, 2008).

The fire-degraded Cerrado areas have lower ETR values in winter, compared to the more preserved Cerrado. In winter, the maximum ETR was 1.34 mm d^{-1}, while in summer, it was 5.31 mm d^{-1}. Therefore, fire practices in the RP-EPA, especially of an agricultural nature, affect water consumption by vegetation in winter, due to the modification of the biotic stage, and the behaviour of the ETR is similar to exposed soil areas (BEZERRA *et al.*, 2008).

In dry forests, the average ETR in winter was estimated at 2.20 mm d^{-1} and in summer at 6.25 mm d^{-1}. This behaviour is related to the phenology of vegetation. In the winter period, it loses its leaf architecture. Consequently, it reduces the LAI (Leaf Area Index), leaving an aspect of dry vegetation, with reduced stomatal conductance and photosynthetic activity (SANTANA *et al.*, 2010).

However, in the rainy season, the plant recovers its leaf system, increasing the transfer of water vapour to the atmosphere (RIBEIRO; WALTER, 1998). The data show that the dry forest is a phytophysiognomy of relevance for the maintenance of water resources since it performs a seasonal control of water loss, and its preservation is substantial for the balance and conservation of water in the hydrological system.

3.2.2. Palm Swamps Veredas

In the Palm Swamp Veredas, half of the ETR values are in the range of 3.21 to 3.36 mm d^{-1} in winter, and 7.05 to 7.35 mm d^{-1} in summer. The natural characteristics of Palm Swamp Veredas contribute to greater ETR. These environments have hydromorphic soils, with groundwater close to the surface, with an intermittent drainage system (COSTA-MILANEZ *et al.*, 2014). Therefore, most of the liquid radiation is absorbed by these environments, mainly due to the water quantity (ALMEIDA *et al.*, 2016; LEITE *et al.*, 2018a).

Although high ETR indicates loss of water due to evapotranspiration, Palm Swamp Veredas areas have a social and environmental function. Several communities use water and perform extractive activities; furthermore, they function as ecological corridors (COSTA-MILANEZ *et al.*, 2014). Therefore, it is necessary to monitor and preserve these environments.

3.2.3. Pastures

In the pasture, the average ETR was 1.61 mm d^{-1} in winter, and 3.28 mm d^{-1} in summer, representing an increase of 50.91%. In winter, half of the ETR values vary between 1.38 to 1.82 mm d^{-1}, while in summer, between 2.89 to 3.82 mm d^{-1}. These variations are in line with other studies (OLIVEIRA *et al.*, 2014). The lower ETR in winter has the effect of lower biomass production in this period, as there is less precipitation, negatively interfering in the production of forage (FAGUNDES *et al.*, 2006).

Considering the ETR rates of pastures, we argue that pasture areas in inappropriate locations can negatively affect the regional environment. For example, the replacement of areas of Wooded Cerrado, a region of sandy soils, with pastures, can generate peak flows if there is low soil cover by grass. Grazing activities can alter the surface layer of the soil, reducing the water's infiltration capacity (BORGES *et al.*, 2009). This behaviour contributes to the loss of water from the environment through two paths, peak flow, and evapotranspiration

3.2.4. Central irrigation pivot

The central pivot irrigation areas have lower ETR in winter among the land use classes (average 0.98 mm d^{-1}). There is a concentration of ETR values between 0.81 to 1.13 mm d^{-1} in winter, while between 5.80 to 6.14 mm d^{-1}. In summer, there is a higher incidence of solar radiation, which influences the increase in ETR. The crop development stages also affect the gain. In irrigated crops, during the growth phase, about 60 to 80% of the liquid radiation is converted to latent heat/evapotranspiration (Suyker and Verma, 2009; Bezerra *et al.*, 2014).

Cultivation types also influence ETR. For sugarcane plantations, there are variations of 4 and 5 mm.day^{-1} (MACHADO *et al.*, 2014). In rice fields of 3.27 to 7.81 mm d^{-1} (SANTOS *et al.*, 2010). In the case of the central pivot, the high ETR values are due to the management technique, as well as regional climatic conditions in the North of Minas.

3.2.5. Eucalyptus

In the eucalyptus areas, the ETR averages were 7.55 mm d^{-1} in summer and 3.22 mm d^{-1} in winter. The winter values showed zero variance, between 3.21 to 3.24 mm d^{-1}. In the summer, the concentration of ETR values was between 7.44 to 7.66 mm d^{-1}, with a deviation of 0.02 mm d^{-1}, as they are very homogeneous areas.

In dry and humid season conditions, ETR can vary depending on the age of the forests, climatic conditions and season (SOUZA *et al.*, 2006; MENEZES *et al.*, 2011). In eucalyptus aged 2 to 4 years in a tropical climate, the ETR varies between 2.90 to 3.40 mm d^{-1} (FACCO, 2004), in a humid subtropical climate, plants with two years showed variation in ETR from 1 to 8.60 mm d^{-1} (SACRAMENTO NETO, 2001).

In the growth phase, the plant uses more significant portions of energy and raises the rates of ETR (REIS *et al.*, 2014). Eucalyptus plantations with a large structural/phenological size and well-defined leaf architecture, present determinant characteristics for these higher rates (XAVIER *et al.*, 2002). Therefore, this explains the higher ETR compared to other classes of land use. In this perspective, studies are showing that the reduction of forest cover of conifers and eucalyptus in small basins, favours the increase of water production, due to the decrease in ETR rates and water consumption (LIU *et al.*, 2016). However, it is essential to emphasise that some studies indicate that the analysis of the impact on water dynamics caused by eucalyptus must take into account the history of land use (ALMEIDA; SOARES, 2003).

Eucalyptus forests tend to consume more water in response to native Cerrado species (LIMA, 1996), due to rapid development. Furthermore, the relief can influence, because in areas with higher elevations, the tendency is that there is an exchange of humid air for dry air with more intensity due to the free circulation of the wind (MCVICAR *et al.*, 2007). In the northern region of Minas Gerais, eucalyptus forests occur at the top of the plateaus (LEITE *et al.*, 2018b). These are aquifer recharge zones. Therefore, the high ETR in these locations can negatively affect water dynamics, and this requires better regulation of the presence of eucalyptus in plateaus.

3.3. Principal Component Analysis

We analysed the sample points of land use by PCA, considering some remote sensing data from the summer and winter periods (**Erro! Fonte de referência não encontrada.**). In the summer and winter periods, the ETR of Woodland Cerradão has a more significant correlation with aerodynamic resistance (Rah), latent heat flow (LE), and leaf area index (LAI). The increase in the LAI indicates that the canopy is well structured, intercepting more significant portions of solar radiation, favouring the conversion of water present in the vegetation structure (liquid state), to the form of water vapour (CUNHA *et al.*, 2002). This behaviour is antagonistic to the flow of sensitive heat (H) (used to heat the air) since the vapour suspended above the canopy of the vegetation causes the cooling effect of the canopy (POTTER *et al.*, 2020).

Dry forests have a relationship contrary to the LAI in the winter period, as the vegetation loses part of the canopy leaves in this period. However, there is an approximation of the points with the variable H, because in winter this phytophysiognomy directs a more significant portion of energy to the heating of the air, increasing the sensitive heat. The Rah, LE, and Rn also have a relationship contrary to the points of dry forest in winter. With the low-density canopy, the Rah reduces; consequently, there is less impediment of heat transport (LE), and the balance of radiation (Rn) is less. In summer, the position of the points approaches Rn and LAI. During this period, there is a restructuring of the canopy (RANKINE *et al.*, 2017).

In Wooded Cerrado, in the summer and winter period, the points are located opposite the aerodynamic resistance variable (Rah), the low structure of the canopy influences this. The low density of leaves implies a lower rate of ETR between the uses analysed in the summer and winter periods (Figure 4). Similar behaviour occurs in fire-degraded Cerrado, because the leaf structure, systematically distorting biophysical variables.

In the summer period, in central pivot irrigation, the points are closer to the LAI, because, in this period, there is higher biomass production. Consequently, the patterns of heat transfer in the air are changed, increasing the resistance to aerodynamics (Rn) and decreasing the sensitive heat flow (H). Most of the available energy (Rn) promotes evapotranspiration (portions of LE).

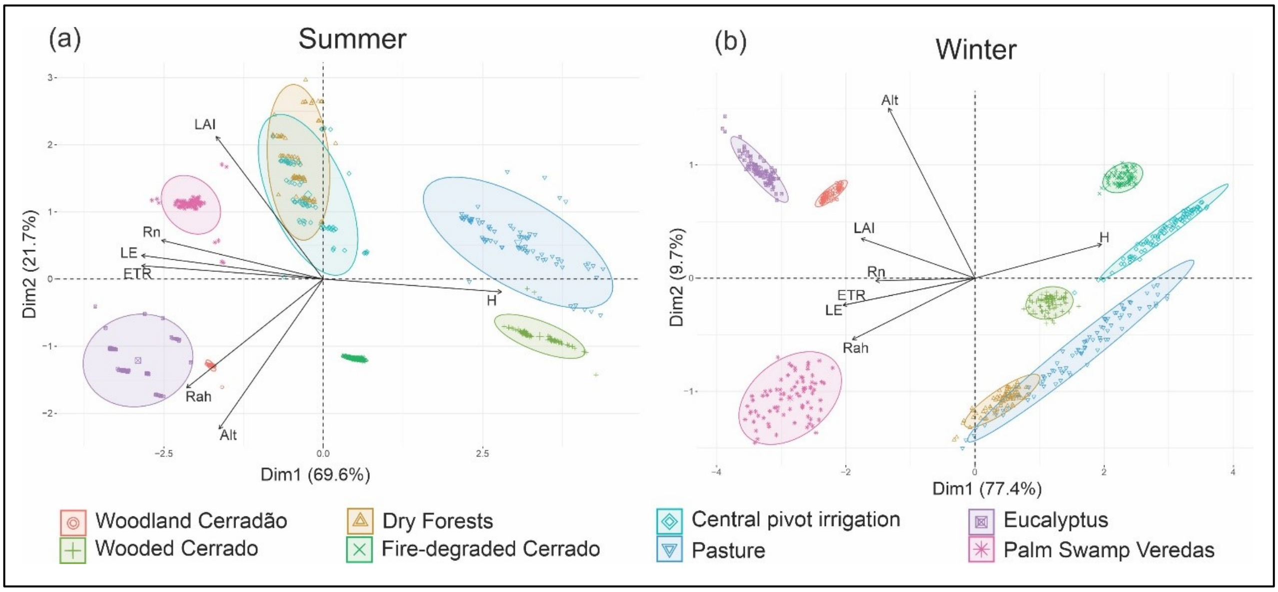

Figure 5 - Biplot with two components (Dim1 X-axis and dim2 Y-axis) for SEBAL biophysical variables, and altitude. (a) summer, (b) winter. (Alt: altitude; LAI: leaf area index; ETR: actual evapotranspiration; H: sensitive heat flow; LE: latent heat flow; Rah: aerodynamic resistance; Rn: reaction balance).

In pastures, the production of biomass is higher in the summer (LAI); this implies a more significant relationship with ETR, latent heat flow (LE), and aerodynamic resistance (Rah), and studies demonstrate this behaviour (FIRMINO *et al.*, 2013). In the winter period, the points are opposite the direction of the LAI (Figure 5). This period has the lowest biomass production (BRITO *et al.*, 2018), and directly correlates with low aerodynamic resistance (Rah).

The sample points of eucalyptus forests are related to LAI and ETR in winter and summer; the well-defined structure of the canopy influences this aspect. The climatic seasonality of the region has little influence on the phytophysiognomy of eucalyptus forests (SILVA *et al.*, 2018). In the winter period, there is a decrease in evapotranspiration patterns, as there is less water availability in the soil. However, when compared with the other classes analysed, in winter, eucalyptus has higher evapotranspiration rates (Figure 3 and Figure 4).

Evapotranspiration in Palm Swamp Veredas has both a winter and summer correlation with the LAI, Rah, Rn and LE. The characteristics of the environment explain this behaviour. There is a high-water availability due to the presence of the water table near the surface (ALENCAR-SILVA; MAILLARD, 2011), and this maintains a higher ETR rate in both periods.

In general, land use forms tend to increase ETR rates in the summer. Consequently, there are changes in the biophysical parameters extracted by SEBAL. However, in the summer, SEBAL variables for classes of anthropic use (fire-degraded Cerrado, central pivot irrigation, pasture, and eucalyptus) maintain more distinct characteristics concerning the forest domain of the region (Wooded Cerrado).

4. CONCLUSIONS

The SEBAL algorithm was effective in estimating evapotranspiration rates, including the extraction of other variables from the model. The PCA demonstrated the relationships between them.

In general, the natural vegetation of the Cerrado favours the maintenance of water during the summer concerning anthropic classes, especially considering that there is a dominance of Wooded Cerrado with low rates of ETR.

The predominance of eucalyptus forests with high rates of ETR in recharge zones can negatively affect the water dynamics of the region. The ETR rates for this use are similar to the areas of Palm Swamp Veredas. The Palm Swamp Veredas have more significant water loss by ETR due to the humid environment of this ecosystem.

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