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Energy balance in areas with different land uses in the Chapada do Araripe

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ABSTRACT
The objective of this work was to assess the energy balance components such as net radiation and sensible, latent and soil heat fluxes by using the Surface Energy Balance Algorithm – SEBAL – through analyses of 13 Landsat 5-TM and Landsat 8-OLI images. The images were obtained from Image Processing Division (DGI) of the National Institute for Space Research (INPE), Brazil, and from the United States Geological Survey (USGS). The meteorological data were obtained from the Barbalha automatic station provided by the National Institute of Meteorology (INMET), Brazil. The study area is located around the Chapada do Araripe (Araripe Plateau) protected forest. Two points with distinct land uses, characterized by irrigated and bare soil areas, were chosen. The net radiation values for the irrigated area ranged from 600.0 to 727.7 W m-2 between the years 1993 and 2014. The soil heat flux values for the bare soil area increased from 52.0 to 94.9 W m-2. The majority of the analyzed images showed sensible heat flux values below 300 W m-2 for the bare soil area. In all images, the average values of latent heat flux were greater than 500 W m-2 for the irrigated area. It is concluded that deforestation processes and intensification of agricultural exploitation that the plateau has been suffering over the years are the main reasons for decreasing latent heat flux values in bare soil areas.

Keywords: Landsat 5, SEBAL, Remote sensing

Introduction

The great majority of the Brazilian Northeast region has a semi-arid climate, characterized by high intensity precipitations in short periods of time, poor spatial distribution and, combined with long periods of drought, affect agriculture, human and animal supplies.

The biophysical characteristics of the surface generate the distribution of energy exchange, thermal regimes of the soil (GOMES; SANTOS; ALMEIDA, 2013), photosynthesis and water evaporation. Their quantities are determined by the available energy defined as the balance of short- and long-wave radioactive exchanges (Silva et al., 2016). Such radioactive surface processes are of great importance for the redistribution of moisture and heat in the soil and atmosphere, which in turn, affect the behavior of weather, climate and biosphere on Earth (Baker et al., 2000).

Over recent years, remote sensing (RS) has become an important tool for obtaining hydrological data. As a result, several RS based algorithms were developed to obtain energy balance components (EB). One of them is SEBAL (Surface Energy Balance Algorithm for Land) proposed by BASTIAANSSEN et al. (1998). It uses satellite images and few surface data to estimate the net radiation (Rn) and soil (G) heat fluxes. The EB components determined with SEBAL are calculated by quantifying the LE density, which is obtained as the residue of the BE equation (LEITE, BRITO, 2012). The use of SEBAL has the advantage of providing energy balance to the surface in an effective and economical manner. It allows a high spatial range and, depending on the orbital sensor that captures

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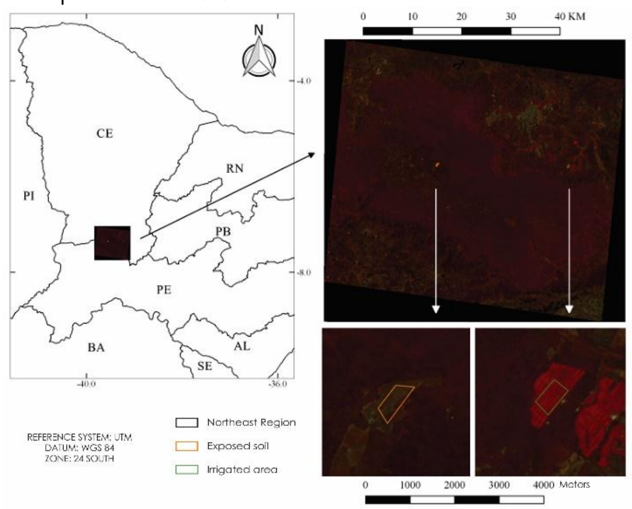
data from the reflective and thermal channels, can grant high spatial resolutions (SILVA et al., 2005).

Based on the above considerations, the objective of this work is to evaluate the components of the Energy balance such as radiation balance and sensible and latent heat fluxes in the soil through the SEBAL algorithm in two distinct land use areas. Thirteen Landsat 5-TM and two Landsat 8-OLI satellites images in the Cariri region of Ceará were analyzed.

Material and Methods

The study area is located around the Chapada do Araripe protected forest. Two points with distinct land uses, characterized by irrigated and bare soil areas, were chosen. A map in the 4R3G2B composition was created by using one single image with orbit track date of 29/08/2011 (Figure 1).

Figure 1 - Map represented the areas of study, composition 4R3G2B.

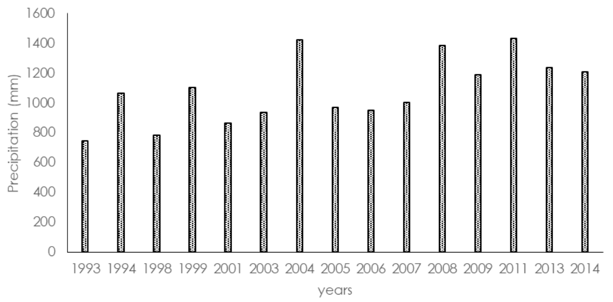


The EB components were obtained using the SEBAL algorithm and a Fortran 90 language program was developed to retrieve data of the study area. The climate of the region is of Aw' type, rainy tropical, with maximum and minimum average temperatures of 34 °C and 18 °C, and maximum and minimum average relative humidity of 80% and 49% respectively (RAMOS; SANTOS, 1993). According to Mont'Alverne (1996), the rainy season is comprised between January and May and the dry season between September and November, with an average annual rainfall of 1,033 mm.

The Landsat 5-TM digital orbital images analyzed in this research were obtained from the National Institute of Space Research (INPE), orbit and point 217/65, with orbital track dates of 11/08/1993, 02/11/1994, 08/09/1998, 08/12/1999, 04/10/2001, 23/08/2003, 12/10/2004, 16/11/2005, 21/12/2004, 2006, 18/08/2007, 21/09/2008, 24/09/2009, and 29/08/2011 and orbit track time of around 9:30 A.M. (local time). The Landsat 8-OLI images at 19/09/2013 and 22/09/2014, obtained from the US Geological Survey (USGS, 2013), with orbital track time of 9:30 A.M, through the onboard OLI (Operational Land Imager) and IRS (Thermal Infrared Sensor) sensors. The bands 2, 3, 4, 5, 6 and 7 have spatial resolution of 30 m and the band 10, corresponding to the thermal infrared band (10.6 – 11.19 μm), has spatial resolution of 100 m. The meteorological data were obtained from the automatic station of Barbalha made available by the National Institute of Meteorology (INMET).

Figure 2 shows the average annual rainfall obtained from the conventional station of Barbalha, managed by the Cearense Foundation of Meteorology and Water Resources (FUNCEME) located in the study area.

Figure 2. Annual precipitation values obtained at FUNCEME at the Barbalha-CE station



The cumulative rainfall 20 days prior to satellite orbit was calculated using data from the conventional station of Barbalha (Table 1).

Table 1 - Cumulative precipitation values 20 in the last 20 days preceding the date of the study images. (Author, 2017)

Dates of images	Precipitation of last 20 days antecedent (mm)
11/08/1993	5.4
02/11/1994	17.3
09/08/1998	0.0
12/08/1999	0.0
04/10/2001	9.8
23/08/2003	0.0
12/10/2004	0.0
16/11/2005	0.0
21/12/2006	5.0
18/08/2007	0.0
21/09/2008	0.0
24/09/2009	0.0
29/08/2011	5.5
19/09/2013	0.0
22/09/2014	1.9

The surface net radiation estimation was performed using the equation of radiation balance (Equation 1).

$$R_n = (1-\alpha)R_{S\downarrow} + R_{L\downarrow} - R_{L\uparrow} - (1-\varepsilon_o)R_{L\downarrow} \quad (1)$$

Where: Rn is the surface net radiation (W m-2),

$R_{S\downarrow}$ is the incoming short-wave radiation (W m-2),

α is the adjusted albedo of each pixel (dimensionless),

$R_{L\downarrow}$ is the incoming long-wave radiation from atmosphere towards each pixel (W m-2),

$R_{L\uparrow}$ is the long-wave radiation emitted by each pixel (W m-2) and

ε_o is the emissivity of each pixel (dimnesionless).

The soil heat flux G (W m-2) was obtained from the empirical equation developed by BASTIAANSSEN et al. (2000) (Equation 2).

$$G = \left[\frac{T_S}{\alpha}(0{,}0038\alpha + 0{,}0074\alpha^2)(1 - 0{,}98NDVI^{4)}\right]R_n \qquad (2)$$

Where: Ts is the surface temperature (°C) and

NDVI is the Normalized Difference Vegetation Index.

Sensitive heat flux (H) estimation is the most complex operation of SEBAL and it is obtained through an iterative process (Equation 3). At first, the atmosphere is considered in neutral equilibrium, followed by the identification of a stability condition and finally promoting the necessary adjustments. The H estimation is initially based on wind speed and surface temperature using the internal calibration of temperature difference near surface according to (BASTIAANSSEN et al., 1998):

$$H = \frac{\rho \cdot c_\rho dT}{r_{ah}} \qquad (3)$$

Where: ρ is the moist air density (1,15 kg m-3),

cp is the air specific heat (1005 J kg-1 K-1),

dT is the temperature difference near surface (K) and

rah is the aerodynamic resistance to the heat transport (s m-1).

The detailed procedures for determining dT and the correction of atmospheric stability can be found in ALLEN et al. (2002).

The latent heat flux LE (W m-2) was obtained by simple difference between net radiation, soil heat flux and sensible heat flux (Equation 4).

$$LE = R_n - G - H \qquad (4)$$

Where: LE is the instantaneous latent heat flux value, that is, its value at the moment when the satellite orbits the point.

Results and Discussion

It is shown in Figure 3 the average values of net radiation over the years for the different land uses. The highest value of Rn for the irrigated area (Figure 3a) was 727.7 W m-2. Nicácio (2008) found similar values (around 731.0 W m-2) for fruit farming irrigated areas in Petrolina-CE using satellite images, also obtained through SEBAL. The values of net radiation for the irrigated area ranged from 600.0 to 727.7 W m-2 between the years 1993 and 2014. Meireles (2007) found Rn values ranging from 600.0 to 700.0 W m-2 in irrigated agricultural areas in the river Acaraú-CE basin.

Figure 3 - Temporal distribution of the radiation balance between 1993 and 2014 for irrigated area (a) and exposed soil (b).

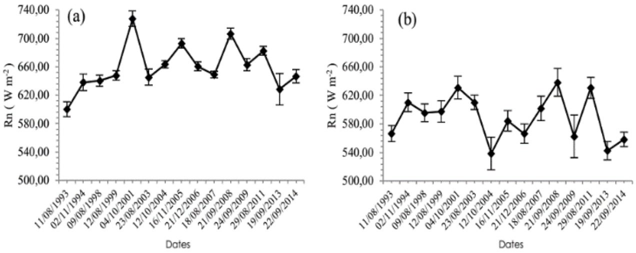


Figure 3 (b) shows that Rn average values for bare soil areas fluctuates between 538.7 and 638.2 W m-2. The reduced vegetal cover provides a lower capacity to reduce surface temperature and directly affects the surface net radiation.

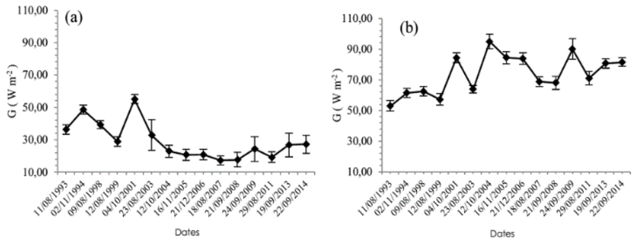
Net radiation is strongly affected by the vegetation and directly proportional to NDVI. Consequently, higher values are expected in areas with larger vegetation cover and smaller values in bare soil areas (MATOS; CANDEIAS; AZEVEDO, 2016).

Soil heat flux (G) is the most troublesome EB component to be accurately obtained through the remote sensing technique although it is not a limiting factor when dealing with small areas. The measurements of G are representative when assuming the soil and the vegetal cover to be homogeneous (FEITOSA, 2005; BASTIAANSSEN et al., 1998).

Being a fraction of the radiation balance, the soil heat flux (G) represents part of the energy that is transferred to the lower soil layers and usually results either in an increase of energy to the environment during nighttime or a decrease during daytime (GALVANI, ESCOBEDO and PEREIRA, 2001).

Figure 4 shows the variation of averaged values of G over the years. Values lower than 60 W m-2 were found in the irrigated areas (Figure 4a). Bezerra (2006), using Landsat images and applying the SEBAL algorithm, found values lower than 75 W m-2 in the same region analyzed in this research.

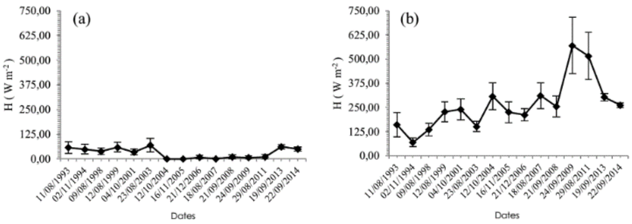
Figure 4 - Time distribution of heat flux in the soil between 1993 and 2014 for irrigated area (a) and exposed soil (b).



The G estimations in the bare soil areas ranged from 52.9 to 94.9 W m-2 (figure 4b). Silva and Bezerra (2006), studying energy balance components in semi-arid regions, obtained averaged values around 103.7 W m-2, for bare soil conditions. The anthropic area presented the highest G averages (Figure 4b) due to the decreasing NDVI and increasing albedo, as shown by equation 2 (ARRAES; ANDRADE; SILVA, 2011).

The temporal behavior of the sensible heat flux (H) for irrigated and bare soil areas clippings is shown in Figures 5 (a) and (b), respectively. Figure 5a shows the representative values for irrigated area lower than 70 W m-2. Bezerra (2006) in a study carried out in the Araripe plateau found values around 60 W m-2 for irrigated areas, which agrees with the values in the present research.

Figure 5 - Temporal distribution of the sensible heat flux in the period between 1993 and 2014 for irrigated area (a) and exposed soil (b).

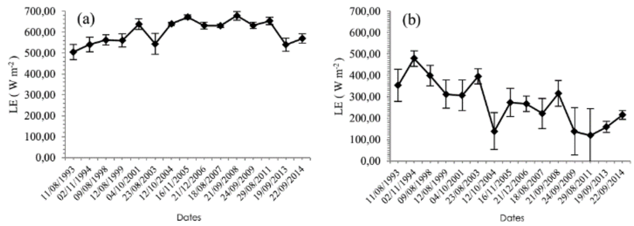


The image with orbital track date of 02/11/1994 shown the lowest value of H (69.7 W m-2) for bare soil (Figure 5b). This low value may have been occurred due to an above average annual precipitation in the region in addition to a cumulative precipitation of 17.3 mm occurred in the previous 20 days (Table 1). Values of H were below 300 W m-2 in most images. It was observed that H averages for bare soil areas were higher than those of the irrigated areas. According to Arraes (2010), such a fact is explained by the absence of vegetal cover in this area, with almost all available energy being used for air and soil heating.

The latent heat flux (LE), defined as the amount of heat used in the evaporation and/or evapotranspiration process, is calculated by the SEBAL algorithm as residue of surface energy balance, that is, it is obtained by the difference between net radiation (Rn), soil heat flux (G) and sensible heat flux (H) (ARRAES, 2010).

The latent heat flux averages were higher than 500 W m-2 for all images. In agricultural areas, high latent heat flux values are expected due to a high water availability, obtained through storage of water in the root zone and irrigation (NICÁCIO, 2008). Bezerra (2006) obtained LE results of around 550 W m-2 for agricultural areas. Rodrigues (2004), in a study that assessed the water requirements and growth of a cotton field crop at Embrapa/Algodão Experimental in Barbalha-CE, obtained G surface values using Landsat 5 images of 450 W m-2 before irrigation and of 580 W m-2 after irrigation.

Figura 6 - Distribuição temporal do fluxo calor latente no período entre 1993 a 2014 para área irrigada (a) e solo exposto (b).



The averages of latent heat flux component (LE) for bare soil are shown in Figure 6b. A decrease in the average values of LE was observed during the period and it may be related to deforestation processes and intensification of agricultural exploitation that the plateau has been suffering over the years. The highest LE average was 479.3 W m-2 at 02/11/1994. Such value can be justified by the occurrence of a cumulative precipitation of 17.3 mm.

Conclusions

The decrease in LE averages for the bare soil areas occurred due to deforestation processes and intensification of agricultural exploitation that the plateau has been suffering over the years.

Satellite images, such as from Landsat 5 and 8, can be used to obtain energy balance components (Rn, G, H and LE) by SEBAL and analyze their temporal variability.

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