Original Article

VALIDATION OF THE NET RADIATION THROUGH SEBAL ALGORITHM IN DIFFERENT CLASSES OF LAND USE AND OCCUPATION IN RIO DE JANEIRO

VALIDAÇÃO DO SALDO DE RADIAÇÃO PELO ALGORITMO SEBAL EM DIFERENTES CLASSES DE USO E OCUPAÇÃO NO RIO DE JANEIRO

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ABSTRACT: The aim of this study was (a) to assess and evaluate the net radiation (R_n) by SEBAL algorithm and (b) to assess the net radiation (R_n) by the landscape's spatial temporal dynamic using ISODATA algorithm, in entire city of Rio de Janeiro. Has been calculated the R_n by using the TM sensor images and orbital platform Landsat 5 and by Penman-Monteith method (FAO 56) with the conventional meteorological station data (EMC). The R_n values obtained with the SEBAL algorithm to the EMC cut area were slightly smaller than those obtained by the Penman-Monteith method (FAO 56), with VM = -36 (Wm^{-2}) and EPE = 84.44 Wm^{-2}. The R_n obtained by SEBAL has a high correlation with the values obtained in the surface. The R_n values obtained with the algorithm for the land use and occupation classes in the city of Rio de Janeiro were similar to those reported by other authors for the same classes.

KEYWORDS: Image processing. Remote sensing. Albedo.

INTRODUCTION

Net radiation (R_n) is the main source of energy response for the heating of the soil and air and the evaporation process (SILVA et al., 2005). Its knowledge is important to for characterizing and monitoring the climate and weather forecast, identifying interactions of radiative fluxes descending and ascending of short and long wave that interact between environmental variables and the surface, in addition to being relevant for formulating public policies (DI PACE et al., 2008; BIUDES et al., 2009; ANDRADE, 2009, SILVA et al., 2011).

There are several conventional devices, such as balance-radiometers, which measure the net radiation *in situ* (GOIS et al., 2016a). However, these devices only present good precision under similar conditions and in small areas (DI PACE et al., 2008). The use of remote sensing (RS) made possible the spatial and temporal R_n monitoring over large areas and with heterogeneous features at a low cost (GOMES et al., 2009).

Among the most commonly used algorithms in heat flux on the surface studies, it stands out SEBAL (Surface Energy Balance Algorithm for Land) proposed by Bastiaanssen et al. (1998a). This algorithm has been used in numerous studies (MORAN, 1994; BASTIAANSSEN et al.,1998a; BASTIAANSSEN, 2000; GRANGER, 2000; SILVA et al., 2011 and 2014; ANDRADE et al., 2014). It can be applied in digital images from any orbital sensor that perform radiance measurements in the visible channels, near and thermal infrared, such as: TM (Thematic Mapper) - Landsat 5 (BEZERRA et al., 2008; MENEZES et al., 2011), NOAA-AVHRR (TIMMERMANS; MEIJERINK, 1999; BASTIAANSSEN; ALI, 2003), MODIS/TERRA/AQUA (DI LONG et al., 2010; SANTOS, 2011; OLIVEIRA, 2012) and ASTER/TERRA (WANG et al., 2005).

However, to improve the accuracy of SEBAL algorithm are necessary parameterization of several equations to better adjust it to the reality of the study area (BASTIAANSSE et al., 1998a; BASTIAANSSE et al., 1998b; ANDRADE et al., 2014; MACHADO et al., 2014; SILVA et al., 2014). This validation is performed by comparison between the estimated and obtained data in the field by onsite measurements of superficial energy flows or using empirical methods, such as Penman-Monteith method (FAO 56).

Based on the above, the study aims to estimate and validate the net radiation through SEBAL algorithm associated with the landscape's spatial temporal dynamics of the city of Rio de Janeiro, state of Rio de Janeiro.

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MATERIAL AND METHODS

The study area was the city of Rio de Janeiro (MRJ), located between latitudes 22° 45' and 23° 50' S, and longitudes 43° 05' and 43° 50' W (Figure 1). The region climate, according to Köppen classification, is "Aw", characterized by dry and cold winters and humid and rainy summers. The annual mean temperature is 23.9ºC and the maximum and minimum are 27.3°C in summer and 21.1°C in winter, respectively, with rainfall around 1,258 mm.year^{-1} and mean number of 124 days with rainfall (ZERI et al., 2011). MRJ presents vegetation of Dense Ombrophilous Forest with predominance of Oxisols with dystrophic and rarely eutrophic features (GOIS et al., 2016b). Still occur litholic soils in parts of the slopes (IBGE, 2012).

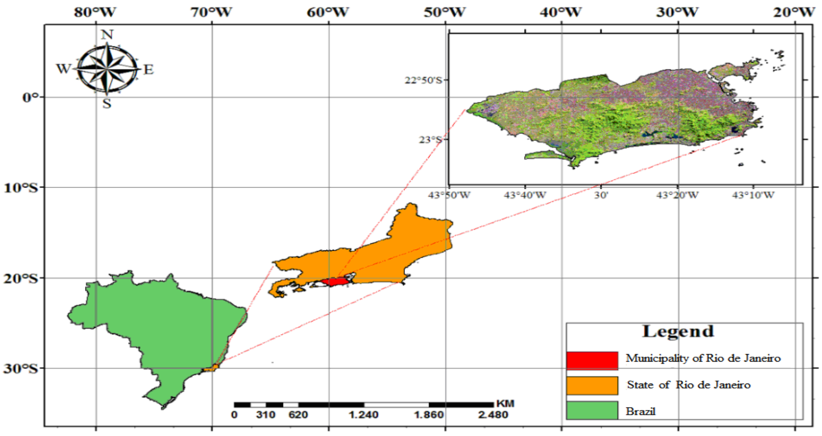

Figure 1. Geographic localization of the study area with mountain ranges.

Five images from the satellite sensor TM Landsat 5 (Table 1) were selected systematically, orbits 217 and point 76 of the series available in Image Catalog in the site of National Institute for Space Research (INPE) (INPE, 2014). The images were based on the lower cloud cover on dates with availability of the following weather variables: mean air temperature ($T_{ar,}$ °C), relative air humidity (UR, %) and insolation (n, hours) through Conventional Weather Station (EMC), whose coordinates are 22° 88' S and 43°18' W and altitude of 11.10 m, located in MRJ (Code - 83743) from National Institute for Meteorology (INMET) (INMET, 2014).

The methodologies adopted by Silva et al. (2014) and Freitas et al. (2012) were used in the unsupervised classification, mapping of land use and occupation in the MRJ with the "ISODATA" classifier for the respective dates. We performed the reclassification of classes in common, grouping them into seven distinct classes, namely: water (areas formed by continental waters and estuaries, lagoons, rivers, canals, reservoirs and dams), flooded area (areas occupied by marshes, shoals, with the characteristic vegetation of these environments), exposed soil (bare ground and unpaved roads), urban area (built-up areas and paved roads), vegetation (tree and shrub forest, in advanced development and regeneration stages), field (areas with undergrowth, graminoid, located on plains or slopes and forest in early development and regeneration stage) and agriculture (different types of annual crops). Subsequently, we converted similar pixels for acreage using ArcGIS software version 10.2. We used in the study six spectral bands 1, 2, 3, 4, 5 and 7, which has a maximum resolution of 30 m, being that one pixel corresponds to 0.09 ha.

Table 1. Technical information on the images used.

Year	Satellite	Sensor	Date	Orbit/Point
1986	Landsat-5	TM	01/28/1986	217/76
1990	Landsat-5	TM	02/24/1990	217/76
2003	Landsat-5	TM	12/29/2003	217/76
2006	Landsat-5	TM	08/31/2006	217/76
2010	Landsat-5	TM	02/15/2010	217/76

In obtaining R_n (Table 2), the images were processed in the ERDAS IMAGINE software version 2014, using the platform Model Maker. We used the standard of SEBAL algorithm (BASTIAANSSEN et al., 1998; ALLEN et al., 2002). On ERDAS IMAGINE 2014, the union of the satellite bands, the radiometric calibration (MARKHAM; BAKER, 1987; CHANDER; MARKHAN, 2009), reflectivity, albedo at the top of the atmosphere, albedo of surface, vegetation index, emissivity of each pixel in the spectral domain of the thermal band, emissivity of broadband, surface temperature, long-wave radiation emitted by the atmosphere and surface and descending short-wave radiation emitted by the atmosphere were calculated. ArcGIS version 10.2 was used for making vector data, database and maps.

Calculation of the long-wave radiation emitted by the atmosphere (RL↓, W. m^{-2}) and short-wave radiation emitted by the atmosphere in the direction of each pixel (RS↓, W. m^{-2}), which make up the R_n, were performed in Excel 2013 spreadsheet.

Table 2. Parameters used in the equations for calculating the net radiation (R_n).

	01/28/1986	**02/24/1990**	**12/29/2003**	**08/31/2006**	**02/15/2010**
Z	38.85	43.20	32.71	44.44	35.43
d_r	0.98	0.98	0.98	1.01	0.99
E	51.15	46.79	57.29	45.56	54.57
T_{air} (K)	301.05	301.10	303.40	295.05	307.15

Legend: Z = Solar Zenital Angle; d_r = Relative distance Earth-Sun (UA); E = Sun Elevation and T_{ar} (K) = Air temperature.

With the R_n obtained from SEBAL algorithm and the calculated from Penman-Monteith method (FAO-56) with the data coming from EMC of MRJ, was evaluated statistical performance through the following parameters: mean relative error (E%), standard deviation (S), coefficient of variation (CV, %), mean bias (MB) and standard error of estimate (SEE).

RESULTS AND DISCUSSION

In Table 3, we observed that the mean values of R_n obtained from SEBAL, in relation to the FAO-56 method, underestimated the values of R_n. Negative MB together with SEE (84.44 Wm^{-2}). However, we emphasize lower variation (CV = 7.59%) for the estimated values of R_n obtained from SEBAL. The E% between the observed and estimated values of R_n was less than 7%, which is in accordance with Daughtry et al. (1990), wherein E% between measurements and estimates of R_n with SR are less than 7%. In a study developed in Ceara, at experimental field of Embrapa, Santos et al. (2010) obtained difference between the observed and estimated R_n of approximately 23%, being considered satisfactory. Relative errors obtained did not represent a validation of SEBAL. However, FAO-56 method, used for validating the results may have errors due to failures occurred by lack of maintenance of the EMC instruments and failures in time series without filling the gaps and the appropriate homogenization of data (OLIVEIRA JÚNIOR et al., 2015).

Table 3. Statistical analysis of the net radiation values (Rn, Wm^{-2}) obtained by Penman-Monteith method (FAO-56) and SEBAL algorithm.

DATE	**FAO56 (Wm^{-2})**	**SEBAL (Wm^{-2})**	**E (%)**	**SEE (Wm^{-2})**	**MB (Wm^{-2})**
01/28/1986	704.42	599.29			
02/24/1990	596.80	569.94			
12/29/2003	716.83	659.25	4.05	84.44	-36.98
08/31/2006	450.41	534.66			
02/15/2010	692.59	613.03			
S	112.17	41.64			
CV%	17.74	7.59			

S: standard deviation; CV: coefficient of variation; E: mean relative error; SEE: standard error of estimate; MB: mean bias.

In Figure 2, proximity between the observed and estimated Rn curves was checked. The curve obtained with the SEBAL is well correlated with the R_n curve from FAO-56 method (r = 0.90), it shows low error of algorithm estimate. In a study in the city of Santa Rita do Passa Quatro, São Paulo, Giongo et al. (2010) obtained correlation higher than 0.95, for R_n registered in the USR towers (sugarcane) and PDG (Cerrado) and the estimated by SEBAL, in the area corresponding to each tower. Tasumi et al. (2008), when estimating R_n of 49 sites from United States (USA), observed an average correlation of 95% between measured and estimated values by SEBAL. Di Pace et al. (2008) also obtained good Rn estimates measured in Brazilian Northeast (BN).

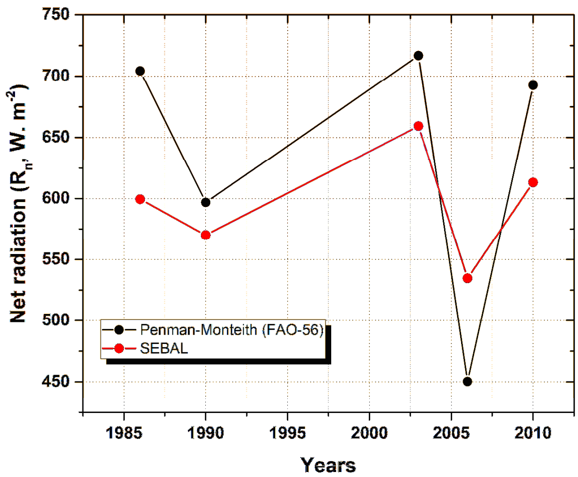

Figure 2. Tendency of observed and estimated values of the net radiation in different years through TM - Landsat 5 images.

Land use and occupation (Figure 3A) and R_n values (Figure 3B) for the period studied, where the light areas indicate smaller R_n values. There was a predominance of vegetation in the main mountain ranges (Pedra Branca, Tijuca and Gericinó) existing in MRJ (GOULART et al., 2015), followed by high R_n values in the evaluated dates. According to Machado et al. (2014) and Caula et al., (2016), vegetation areas have lower albedo values, reflecting a smaller percentage of RS↓, followed by a lower loss by RL↓ due to having lower temperatures, favoring the energy availability in the form of net radiation. Lowland regions of MRJ are predominantly occupied with urban area and, consequently, there is little vegetation area (GOULART et al., 2015). Concomitantly, these areas showed low R_n values (Figure 3B). Similarly, in the Alto Rio Negaro basin, located at Planalto Norte Catarinense and Primeiro Planalto Paranaense, Uda et al. (2013) found smaller R_n values observed in areas with lower biomass density (with Soil Adjusted Vegetation Index - SAVI positive and close to zero) and higher albedo. These authors found higher losses of RL↓ in urban areas, due to higher surface temperature, low biomass density and higher albedo, which favors higher radiation loss to the atmosphere and its lower storage.

Increased urbanization related to reduction of vegetation can cause serious impacts to the studied area. Andrade and Corrêa (2014) found that the reduction in vegetation cover cause changes in the soil flow. This is due to greater exposure of this radiation, increasing the air flow and decreasing the R_n to surface, consequently evaporation process. Thus, cloud formation and the hydrological regime in the region are affected, which makes the local atmosphere becomes warmer and with less moisture content.

Andrade and Corrêa (2014) found a significant variation of R_n values between vegetation and urban areas in the city of Santarém, PA, Brazil. However, R_n s not influenced only by the total incident solar radiation, but also by topography and type of surface coverage (DI PEACE, 2008). In addition, Delgado et al. (2013) observed that there is a characteristic thermal variation between the land use and occupation classes, and therefore, it is possible to classify each type of coverage according to the thermal behavior, being the class with the highest warming formed by areas with human impact, followed by the pasture class.

In Table 4 are presented the values obtained with the extraction of the R_n calculated by SEBAL from polygons of use and soil cover classes for MRJ. Among all the classes, the water showed the highest mean values of R_n, from 566.49 Wm^{-2} to 711.96 Wm^{-2}. Silva et al. (2005) found R_n of 751.3 Wm^{-2} in Sobradinho lake, and mapping the net radiation from Alto Rio Negro basin, Uda et al. (2013) obtained mean R_n of 610 Wm^{-2} for the same class.

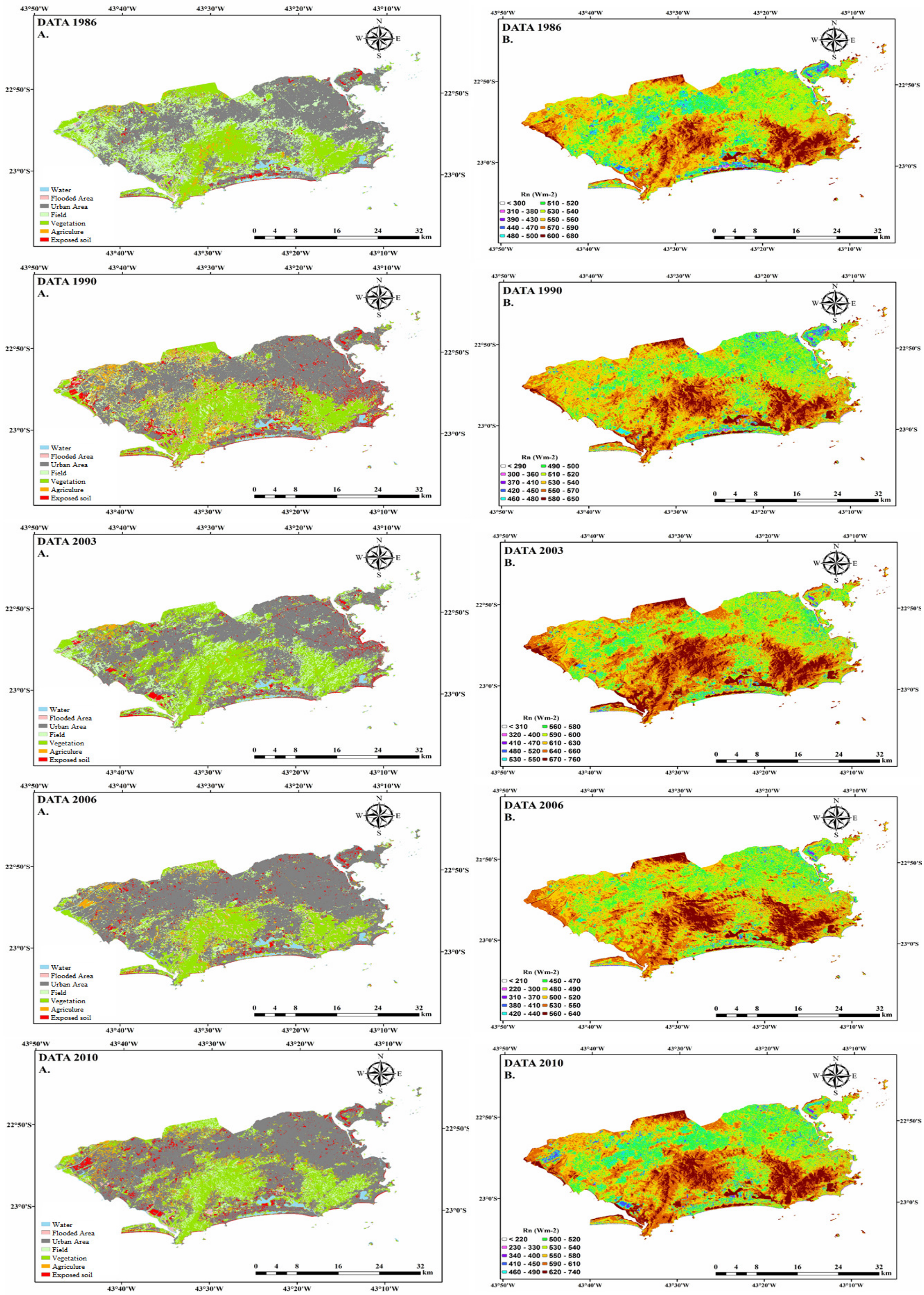

Figure 3. Maps of land use and occupation (A) and net radiation (Rn, Wm^{-2}) (B) of the city of Rio de Janeiro, RJ, in years 1986, 1990, 2003, 2006 and 2010.

Table 4. Mean value of net radiation (Wm^{-2}) for different land use and occupation classes in the city of Rio de Janeiro, RJ.

Date	Water	Flooded area	Vegetation	Field	Agriculture	Urban area	Exposed soil
01/28/1986	609,87	586.97	572.96	551.76	548.01	522.71	417.92
02/24/1990	603,13	582.04	563.36	534.99	525.67	504.03	517.00
12/29/2003	711,96	668.83	647.32	644.16	606.05	591.82	535.62
08/31/2006	566,49	573.42	544.86	531.75	498.25	488.65	424.98
02/15/2010	640,60	612.58	598.43	601.83	562.85	531.96	440.50

The class flooded soil, vegetation and field show the highest Rn values (Figure 5). For flooded area, we obtained R_n of 573.42 Wm^{-2} in August 2006, with the higher R_n in December, 2003 (668.83 Wm^{-2}). Machado et al. (2014) found R_n between 600 Wm^{-2} In August 2006, and 750 Wm^{-2} in January 2011, in mangrove area. Vegetation area showed Rn between 544.86 Wm^{-2} and 647 Wm^{-2} and the field class showed Rn between 531.75 Wm^{-2} to 644.16 Wm^{-2}. These net radiations are similar to those obtained in other studies, in which Oliveira (2009) obtained values higher than 650 Wm^{-2}, respectively, for vegetation areas with higher density and water bodies in Hydrographical Basin of Moxotó River in semi-arid northeast region, Uda et al. (2013) found mean R_n of 526 Wm^{-2} for native forest.

Net radiation obtained for agriculture, urban area and exposed soil were similar to those found by other authors. In area cultivated with sugarcane crop in four different biomes in the State of São Paulo, Silva (2009) obtained 570.9 Wm^{-2} and 309.9 Wm^{-2} in February 22, 2005 and July 16, 2005, Uda et al. (2013) obtained R_n of 444 Wm^{-2} for agricultural area in Alto Rio Negaro basin R_n computed in urban class were similar to that obtained by Moreira et al. (2011), who observed R_n lower than 632 Wm^{-2} in urban areas and higher than those obtained by Uda et al. (2013), who obtained R_n 404 Wm^{-2} and 429 Wm^{-2}.

The obtained exposed soil areas are according to the reported in the literature, wherein Gusmão (2012) obtained R_n values of 425 W.m^{-2} and 500 W.m^{-2}. Values around 420 W m^{-2} were found in exposed soil by Silva et al. (2005). On the coast of Pernambuco, Machado et al. (2014) obtained R_n values ranging from 450 Wm^{-2} in 2006 and600 W m^{-2} in 2011 in exposed soil areas. These smaller R_n values are due to higher albedo values and surface temperature checked in exposed soil areas that consequently reduce the net radiation (MACHADO et al., 2014; OLIVEIRA JÚNIOR et al., 2015).

In Figure 4 are showed R_n obtained for the land use and occupation classes of MRJ. There is a relational pattern between R_n obtained for each class used, on the respective dates. Classes of lower albedo as water, flooded area and vegetation showed the highest R_n values, unlike the higher albedo classes as urban area and exposed soil, which showed the lowest R_n values. According to Uda et al. (2013) and Santana et al. (2016), urban area and exposed soil classes have characteristics opposite to water bodies, this corresponds to areas with greater loss of energy by reflection and emission.

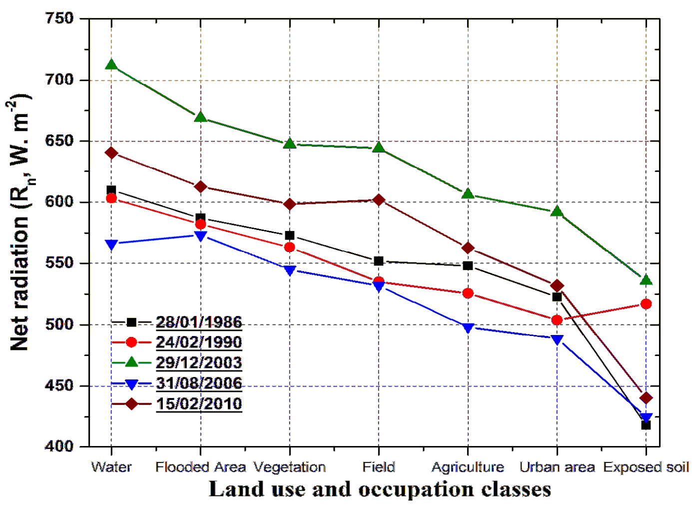

Figure 4. Net radiation obtained for each land use and occupation class.

The greatest R_n values of 12/29/2003 may be a result of this day have been the hottest among the studied dates, with temperature of 30.25°C. Lower R_n observed in urban and exposed soil area also reflected in higher surface temperature. Areas with the highest soil exposure to radiation present lower R_n, and consequently higher air temperature values near the surface (ANDRADE; CORRÊA, 2014).

CONCLUSIONS

SEBAL algorithm is perfectly applied to the city of Rio de Janeiro based on low spatial resolution images for estimating the net radiation.

The calculation of the energy balance via SEBAL algorithm reaches quantitatively and spatially differentiated using ways of the net radiation for different types of land cover in different periods and weather conditions.

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RESUMO: Os objetivos do estudo foram (i) estimar e validar o saldo de radiação (R_n), por meio do algoritmo SEBAL e (ii) avaliar o R_n, através da dinâmica espaço-temporal da paisagem, baseado no algoritmo ISODATA, em todo o município do Rio de Janeiro (MRJ), Rio de Janeiro. Foi calculado o R_n baseado em imagens do sensor TM e plataforma orbital Landsat 5 e, através do método Penman-Monteith (FAO 56) com dados de entrada obtidos da Estação Meteorológica Convencional (EMC). Os valores de R_n obtidos com Algoritmo SEBAL para o recorte da área da EMC foram ligeiramente inferiores aos obtidos pelo método Penman-Monteith (FAO 56), apresentando VM = -36 (W.m^{-2}) e EPE = 84,44 W.m^{-2}. O R_n obtido pelo SEBAL, apresentou alta correlação com os valores obtidos em superfície. Os valores de R_n obtidos com o algoritmo para as classes de uso e ocupação do solo do município do Rio de Janeiro foram semelhantes aos encontrados por outros autores para as mesmas classes.

PALAVRAS-CHAVE: Processamento de imagens. Sensoriamento remoto. Albedo.

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