DETECTION AND MONITORING OF HEAT ISLAND IN THE METROPOLITAN AREA OF RIO DE JANEIRO (MARJ) FROM THE INDICES NDVI AND IBI

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ABSTRACT:

The urban areas of large cities are subject to constant environmental problems. The metropolitan area of Rio de Janeiro (MARJ) is no exception to this situation and faces fundamental problems in the water resources and atmosphere areas. This work investigates the thermal field in the MARJ and corresponding formation of heat islands in the 2000s. Land surface temperature (LST) is calculated from Landsat images. In addition, the vegetation index (NDVI) and the built-up areas index (IBI) are jointly used to establish relationships with respect to metropolitan land use. The results show that higher temperatures are located in areas of greater coverage of urban use, ratified by the high rate of IBI and low NDVI. The urban areas are suitable for the formation of urban heat island.

1. INTRODUCTION

The heat island is one of the most significant phenomena in recent decades under the framework of research on urban environmental dynamics (Arnfield, 2003; Kanda, 2006). Progress in the area of monitoring hydrometeorological variables applied to the field of urban climatology has been achieved lately through the use of remotely sensed images (Voogt and Oke, 2003).

In satellite images, the boundary of the urban heat island can be defined through the radiometric temperature, coming from the thermal band sensors (Weng e Quattrochi, 2006). From the thermal field, maps of spatial distribution of temperature are constructed to analyse the configuration of the heat island effect in urban space.

In conjunction with thermal maps, various indices can be used to complement the evaluation of the heat island. For example, vegetation index, which estimates the amount of green area, such as NDVI, SR, PVI, SAVI, ARVIEU, GEMI and EVI (Ponzoni and Shimabukuro, 2009), provide important support in the analysis. In addition, rates of urbanized area, which calculate the amount of building area, are increasingly used as the NDBI, IBI and ISA (Xian and Crane, 2006; Xu, 2008).

This study aims to analyse the heat island in the metropolitan area of Rio de Janeiro (MARJ) over the first decade of the century XXI through the spatial and temporal evolution of the vegetation index NDVI and also by means of the index IBI for urbanized area.

2. METHODOLOGY

In this research, fifty-four (54) Landsat-5 and Landsat-7 images between 2001 and 2010 were selected, preferably with no clouds and no noise. All images are located in the orbit-point 217-76, covering MARJ.

The images came initially through a digital processing in the computer code SPRING version 4.3. In the next step, the images were georeferenced through a geometric correction procedure using a polynomial model and an interpolation method based on the nearest neighbour to the WGS84 reference ellipsoid.

A map of land use was generated for the decade 2000, using an image acquired in August, 02, 2007, free of clouds. The classifier Bhattacharya method was adopted for the classification of land use. At the end of processing, four classes were extracted: urban, rural or urban low density, vegetation and water bodies.

A map of land surface temperature (LST) representative for the decade was prepared. The calculation of the LST is obtained by Equation (1), where Ts is the LST in Kelvin (K), is the brightness temperature in channel 6, and is the correction factor to obtain the LST from the brightness temperature in thermal infrared channel 6 (between 10.4 and 12.5 µm) of Landsat, as follows:

$$T_S = T_b + \Delta T \tag{1}$$

The calculation of LST requires to pursue steps such as radiometric correction, cloud masking and atmospheric correction, broken down in detail in previous studies (Lucena et al., 2010a; Lucena et al., 2010b).

A map of NDVI was made representing the entire decade 2001-2010. The vegetation index NDVI is achieved through the reflectance in channels 3 and 4 of the sensor, as shown below in Equation (2):

$$NDVI = \frac{\rho_4 - \rho_3}{\rho_4 + \rho_3} \tag{2}$$

A map of IBI, index for built-up areas, was also made for the 2000s, obtained using Equation 3 as

$$IBI = \frac{2\rho_5/(\rho_5+\rho_4) - [\rho_4/(\rho_4+\rho_3) + \rho_2/(\rho_2+\rho_5)]}{2\rho_5/(\rho_5+\rho_4) + [\rho_4/(\rho_4+\rho_3) + \rho_2/(\rho_2+\rho_5)]} \tag{3}$$

The channels 2 and 5 corresponds to the visible (green) and the near infrared (MIR), respectively of the electromagnetic spectrum.

As standard indices, the results for NDVI and IBI are expressed between -1.0 and +1.0, with positive values close to 1.0 as indications of vegetated area (urban), while negative values and close to -1.0 as indications of less vegetated area (urban).

Three maps of LST, NDVI and IBI summarize the results, which represent the 2000s, by using the technique of the maximum value – CMV (Holben, 1986). This technique is important because it eliminates contaminated pixels, even after been applied the masking of clouds and atmospheric correction. The values tend to be low for contaminated pixels, allowing the technique CMV to select the pixel with less contamination.

A table with the means for LST, NDVI and IBI, by type of land use, was developed (Table 2.1). Especially for the LST, the heat island was calculated from the difference between the class "urban" and class "vegetation".

Table 2.1. Total composition of the mean maximum and standard deviation (SD) for the TSC, NDVI and IBI in the 2000s and between classes of land use in the MARJ

Class	Statistical	LST	NDVI	IBI
Urban	Mean	51,0 ^{o}C	0,47	0,17
	SD	3,8 ^{o}C	0,17	0,07
Vegetation	Mean	44,0^{o}C	0,74	-0,01
	SD	2,6 ^{o}C	0,05	0,11
Rural or Urban low density	Mean	46,1^{o}C	0,69	0,09
	SD	2,9 ^{o}C	0,06	0,07

In this work, the hypothesis is that the heat island is a measure of difference, calculated as the deviation between the highest and the lowest temperature, both identified in the same chronological time and spatial area of the image. It is assumed that the higher and lower values of temperature are in those classes, respectively. Thus, the map-product of LST represents only the absolute temperature recorded by the algorithm, which determines the values and the corresponding spatial distribution of the thermal field in MARJ. Therefore, the thermal field will present evidence of heat islands in the space of MARJ.

3. RESULTS

The heat island reached its maximum intensity of 6.7 °C, concentrated in more urbanized areas of MARJ (Figure 1). In these areas, absolute values of surface temperature are above 50 ° C. However, in areas more distant from the urban centre on the outskirts and suburbs of the metropolis, there are also recorded values of the thermal field, though occasional, close to 50 °C. Milder enclaves, with temperatures well below 30 °C, can be found in the largest vegetated areas, as in the vicinity of massive coastal slopes of the mountains in the far north and urban parks (Figure 2). These areas are prone to concentrate the urban island of freshness in contrast to the urban heat island.

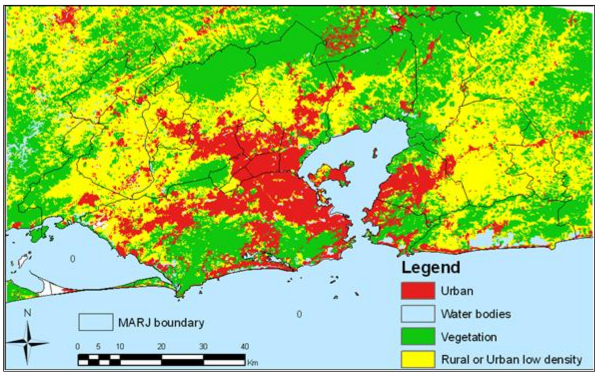

Figure 1. Land use for RMRJ in the 2000s

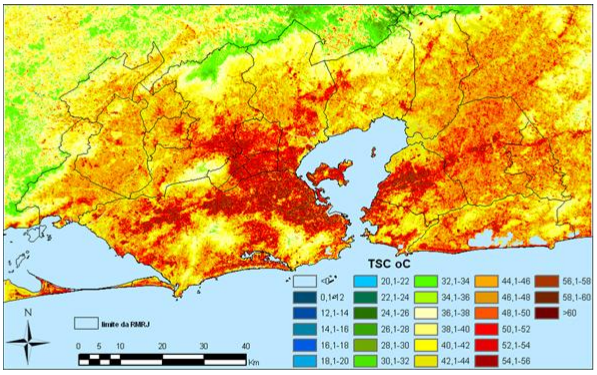

Figure 2. LST map of RMRJ in the 2000s

The NDVI map shows lower values, close to zero, in the most urbanized metropolitan core (Figure 3). However, as the results for the thermal field, low values are found toward the suburbs and outskirts of MARJ, areas of intense mixture of land uses. The highest values of NDVI, close to 1, are concentrated in large patches surrounding the urban and extensive green areas and the massive mountains.

The map of IBI presents relatively high values, above zero, for large areas (Figure 4). In addition to the core metropolitan more urbanized, large suburban areas in the far west, east and north are stained with IBI above zero. This fact can be explained by the composition of the index equation that takes into account not only the construction area (the NDBI), but the vegetation and urban water (NDVI and MNDWI, respectively). Thus, the negative values of IBI are restricted to large vegetated areas of the massive mountains, protected areas and urban parks. On the other hand, the IBI´s higher values, above 0.4, are located in special enclaves of MARJ, as in areas of major economic enterprises such as the petrochemical complex (COMPERJ) in Itaboraí at the northeast sector.

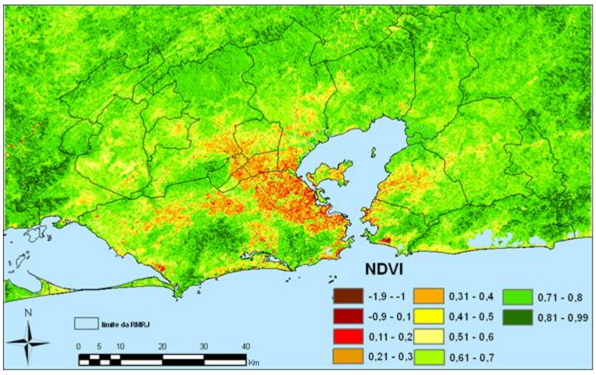

Figure 3. NDVI map of RMRJ in the 2000s

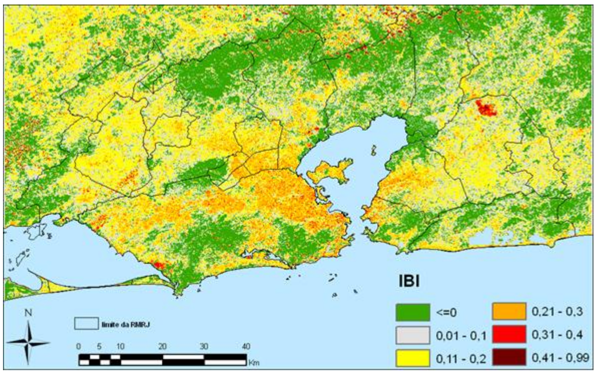

Figure 4. IBI map of RMRJ in the 2000s

4. CONCLUSIONS

The warmer areas, where the maximum intensity of heat islands was established, were located in the central area of the metropolis, with the largest urban land use. However, in peripheral areas, the heat island was also remarkable. This result demonstrates a new spatial pattern of urban heat island, whose nucleus is not restricted to the metropolitan centre, but includes other commercial sub-centres of the suburb and of the metropolitan periphery. This pattern breaks the model of classical heat island of temperate countries, where the core of the heat island is restricted to the central part of town.

The NDVI and IBI indices are important auxiliary indicators for the analysis of the spatial distribution of temperature. The analysis shows that the more urban areas, revealed by the IBI, are prone to higher temperatures, while vegetated areas, as indicated by NDVI, correspond to milder temperature spots. Thus, high values of IBI are potentially associated with the manifestation of heat islands, while high NDVI values identify potential situations of freshness islands.

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