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Mapping of the spatial-temporal change for vegetation canopy in rough relief areas

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ABSTRACT

The purpose of this paper is to present a way of mapping the changes happened in regions with vegetation canopy by means of multiespectral images, using a methodology especially designed for rough relieves, where generally the landforms work as an obstacle for the solar radiation propagation, providing the occurrence of shaded areas. The detection of vegetation areas is not efficient using only techniques as the Normalized Difference Vegetation Index (NDVI). In order to illustrate the mapping proposed technique, it was designed a map that shows the alteration in vegetation cover in the city of Rio de Janeiro whose relief is mostly made up of hills. The set of techniques for determination of vegetation which will overcome the limitations caused by shaded areas is based upon the overlay of the results from the Normalized Difference Vegetation Index (NDVI) and the shaded areas calculated from the Digital Elevation Model (DEM) for verifing the existence of vegetation in regions with low brightness at the moment of the image's capture by the satellite. Then, it will be possible to verify the existence of vegetation areas even in low illumination regions. These techniques were applied on a series with time interval of ten years using Landsat images considering the period from 1985 to 2015. The combination of the NDVI and DEM images with different insolation directions allowed more consistent results with the vegetation's reality, reaching more than 97% accuracy. The final product of this work corresponds to a map that identifies the change in vegetation during these 30 years.

KEYWORDS: Vegetation Canopy. Remote Sensing. Shaded Vegetation Detection. NDVI.

INTRODUCTION

Technological advances in remote sensing as well in space researches is allowing sensors, increasingly accurate and with well detailed spectrum bands, to collect information from the Earth's surface through satellite images, providing repeatable and consistent data, being useful for various applications (NOVO, 2010).

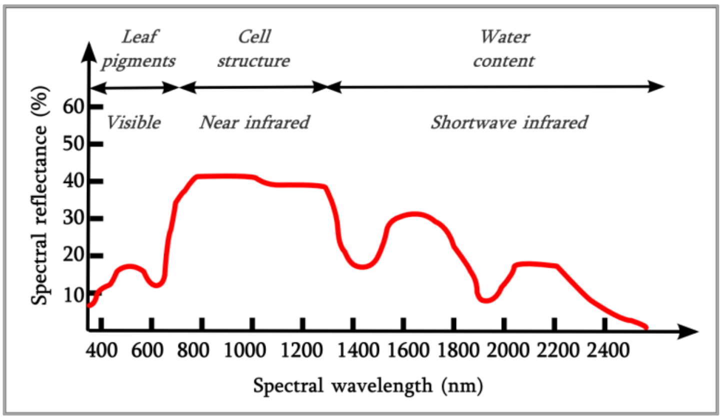
The vegetation indices correspond to mathematical operations between the spectral bands of remote sensing data. A vegetation index should convey useful information about the structure and state of the vegetation, being sensitive to the density and distribution of leaves, mineral composition and health of plants. On the other hand, this index should be insensitive to factors that may affect the radiation reflected by the Earth's surface and captured by the sensor. Examples of these factors are soil characteristics, solar lighting and weather conditions (LIANG, 2004).

The different materials existing in nature can be distinguished by their spectral signature (NOVO, 2010), i.e., the relative intensity of the incident radiation that is reflected (more commonly known as reflectance) considering different ranges of wavelengths.

In the case of vegetation canopies, in the visible range, the reflectance values are relatively low due to the action of photosynthetic pigments that absorb the electromagnetic radiation to perform photosynthesis, nevertheless, in the near infrared (NIR) region such values have to be high due to the radiation's scattering caused by the leaf morphological structure. In the short-wave Infrared (SWIR) band has a further fall in these values due to the presence of water in the sheets (INPE, 2001).

Figure 1 shows the average spectral signature graphic for vegetation. Their values can vary according to the type of vegetation, but the curve is characterized by having low reflectance in the red range and high reflectance in the near infrared range.

Figure1 – Spectral signature for vegetation



Source: Adapted from Gaussman (1977).

The Normalized Difference Vegetation Index (NDVI) corresponds the difference between the near infrared band (NIR) minus the red band (R) divided by the sum of both,

$$NDVI = \frac{NIR - R}{NIR + R} \quad (1)$$

The NDVI was initially employed for Deering in 1978 (ROSENDO, 2005) in order to minimize the effect of oblique illumination and produce a measuring scale ranging from -1 to +1, where, for vegetation, its value tends to be greater than zero.

The development of vegetation behavior can be performed by time series, i.e., a sequence of observations over time (PIMENTEL, 2014). An application example of time series is the Brazilian Amazon Deforestation Calculation Program (PRODES) developed by the National Institute for Space Research (INPE), which produces estimates of annual deforestation rates in the Amazon forest from satellite data (CÂMARA et al., 2006).

The role of cartography, in this context, is to represent the dynamics of vegetation cover, in other words, its evolution in time and space (ORMELING, 1989). It allows the diagnoses and predictions for support to the territorial and environmental management.

The aim of this paper is to propose a methodology to build maps that approaches the spatio-temporal evolution of vegetation, taking into account the characteristics of the relief, the existence of clouds and image noise. The result of this work will ensure more accurate estimates helping to solve environmental problems.

For regions with the incidence of shade provided by rugged relief, only the use of vegetation index (for example, NDVI) is not sufficient to say that a region corresponds to vegetation.

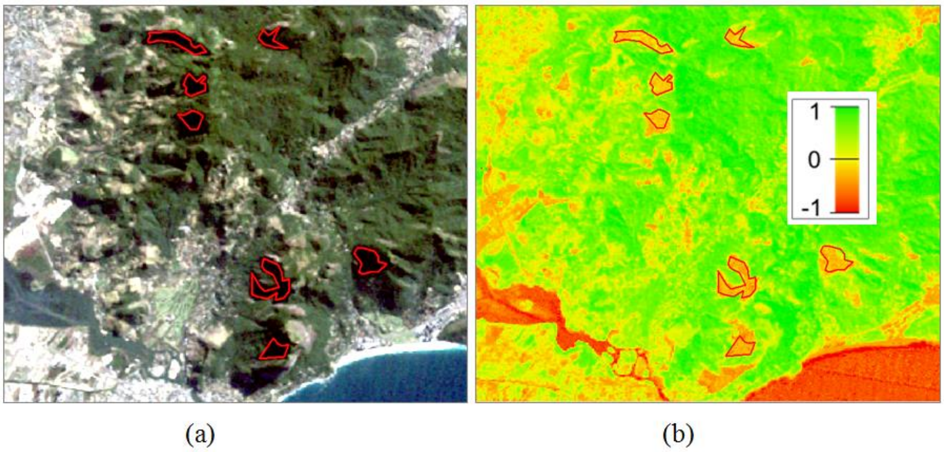
This statement can be exemplified in the city of Rio de Janeiro - Brazil, where Figure 2 shows some areas of vegetation in a rugged relief.

Figure 2 – Example of rough relief area with vegetation canopy

Source: Own authorship (2015).

Figure 3 (a) corresponds to a Landsat 5 image and the regions bounded by red lines indicate the occurrence of vegetation shaded areas. In Figure 3 (b), these regions have NDVI values lower than zero (near the color red), contrary to what is expected to vegetation areas, i.e., values closer to the value 1 (green).

Figure3 – a) Satellite image of a region of Rio de Janeiro; b) NDVI

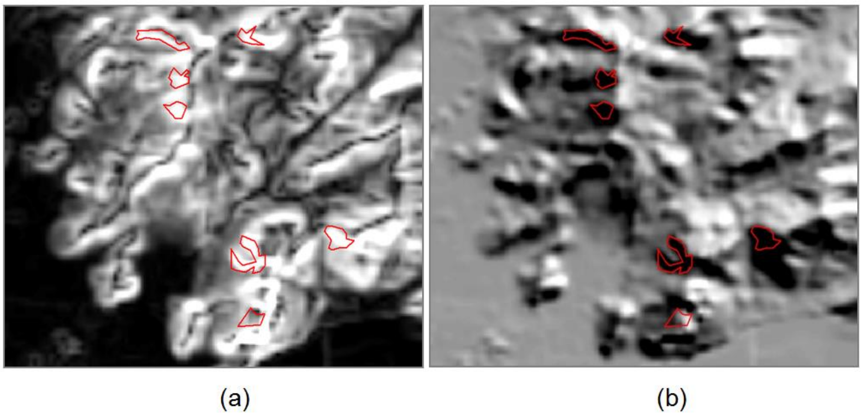


Source: Own authorship (2015).

Assuming that the occurrence of vegetation is more likely in areas with steep slopes (greater than 15 °), mainly due to the difficulty of occupation and land use (SCHIRMER & TRETIN, 2013), it is possible to infer that the shaded areas with high slope characterize a surface with vegetation, at least in most cases for the region under study.

Hence, the proposed solution to complement the identification of vegetation cover in shaded regions is based on the Digital Elevation Model (DEM) by means of the slope image's generation (Figure 4a) and the shaded relief image (Figure 4b), which simulates objects' spectral response at the time of acquisition by the sensor, i.e., the solar lighting levels for each point in the image through the knowledge of the sun position (elevation and azimuth) for that exact moment.

Figure 4 – a) Slope Image; b) Shaded relief image



Source: Own authorship (2015).

Thus, from the two images obtained by the DEM, it is possible to collect samples (pixel values for each band) of shady areas and steep slopes in the satellite image (corresponding mostly to vegetation) and these samples using one of the classification techniques to determine all the shaded vegetation areas, which would hardly be identified using only conventional techniques as the NDVI. The end result tends to be more coherent and consistent with reality, since it combines the vegetation image obtained by the NDVI with the shaded vegetation image (FRANÇA, 2014).

Another factor that strengthens the effectiveness of the methodology is the using of a set of images for each year of the analyzed area, however with different shade positions, knowing that the sun varies its position (azimuth and elevation) during the year, i.e., it is possible to identify areas that do not correspond to vegetation and were obscured by shadow in one image, but that were not in another. At the same step, the effects caused by noise or by the occurrence of clouds are virtually eliminated in the analysis' final result because a pixel with noise or affected by cloud at one epoch probably it will have a different result at other epoch.

The Table 1 presents the variation of sun's elevation and azimuth accordingly each date and hour for all satellite images used in this work. These variations produce different shadow perspectives in each image.

Table 1 – Different values of solar elevation and azimuth for satellite images

SENSOR				SUN	
Sequence	Satellite	Date	Hour	Elevation	Azimuth
1	Landsat 5	15/04/85	12:22:17.7840380Z	40.53	52.72
2	Landsat 5	04/07/85	12:21:59.7520560Z	30.55	42.35
3	Landsat 5	05/08/85	12:21:45.4050440Z	34.54	47.61
4	Landsat 5	28/01/86	12:19:05.8430690Z	50.61	91.11
5	Landsat 5	01/10/94	12:08:05.7280310Z	47.57	68.14
6	Landsat 5	11/04/95	12:01:06.6390560Z	37.30	58.83
7	Landsat 5	27/04/95	12:00:25.4890380Z	34.35	53.00
8	Landsat 5	16/07/95	11:56:46.0690940Z	27.18	48.55
9	Landsat 7	29/03/05	12:41:40.0195733Z	47.42	56.01
10	Landsat 7	17/06/05	12:41:26.0579266Z	33.51	37.19
11	Landsat 7	04/08/05	12:41:22.9789982Z	37.58	43.22
12	Landsat 5	28/08/05	12:40:05.9100500Z	43.71	49.19
13	Landsat 5	16/11/05	12:40:25.3230630Z	62.15	87.15
14	Landsat 8	27/12/14	12:52:04.4374756Z	61.83	96.93
15	Landsat 8	12/01/15	12:52:02.5453793Z	59.98	93.93
16	Landsat 8	13/02/15	12:51:48.3976213Z	56.37	79.47
17	Landsat 7	28/05/15	12:51:28.5593777Z	36.94	35.46
18	Landsat 8	05/06/15	12:51:10.9372631Z	35.86	35.04

Data tabulation: Own authorship (2015). Image source: USGS a (2015)

MATERIALS AND METHODS

For this work, the materials are geospatial data for elements that are involved in the analysis, namely: the limits of the city, the DEM, polygons with samples of vegetation and sets of satellite images.

The city limits correspond to a file in shapefile format, describing the geographical boundaries of the area to be mapped, in this work corresponds to the city of Rio de Janeiro. With this file it is possible to determine the bounding box for selecting a spatial clipping from raw satellite images. This file was obtained from the IBGE downloads webpage (IBGE, 2014).

The used DEM is the ASTER Global Digital Elevation Model in geotiff format. It can be obtained from the USGS Earth Explorer webpage with a spatial resolution of 1 arc second (approximately 30 m at the equator). The ASTER DEMs were obtained by the stereoscopic pairs of satellite images and ensure a vertical accuracy between 10 and 25 meters. The values in your pixels correspond to the elevations referenced to the geoid EGM96 and horizontal datum WGS84. (USGS b, 2014).

The polygons with sample of vegetation correspond to a shapefile created by the operator, so that each polygon of that file necessarily covers an area of vegetation that remained approximately the same pattern (no change) during the analysis time interval of the time series based on the available satellite images. This pattern will be used to determine NDVI threshold values for image classification.

The sets of satellite images correspond to, at least, three images per year, specifically for the years 1985, 1995, 2005 and 2015, and preferably in time intervals of about three months each year. These images must be free of clouds or at least free in the study area. These images are from the Landsat satellite group, they are obtained by the USGS Global Visualization Viewer webpage (USGS a, 2015).

DEFINITONS

The definition of the Coordinate Reference System (CRS) of the materials is necessary, therefore, to perform geoprocessing such data, they must be in the same CRS.

The transformation of a raster image to a new CRS can imply in resampling and, hence, in the loss of the original pixel values. Therefore, the satellite images CRS was taken as a reference and all other data were transformed to this CRS, which in the case of this work is the projected coordinate system UTM 23S WGS84.

The spatial resolution is a numeric value corresponding to the pixel size, that is, the sampling unit for the operations between the images. Most Landsat bands have a resolution of 30 meters, on the other hand, the DEM has a resolution of 1 arc second. For this reason, these images have to be resampled in order to coincide in spatial resolution and pixel center. Thus, the spatial resolution adopted in this study was 30 m.

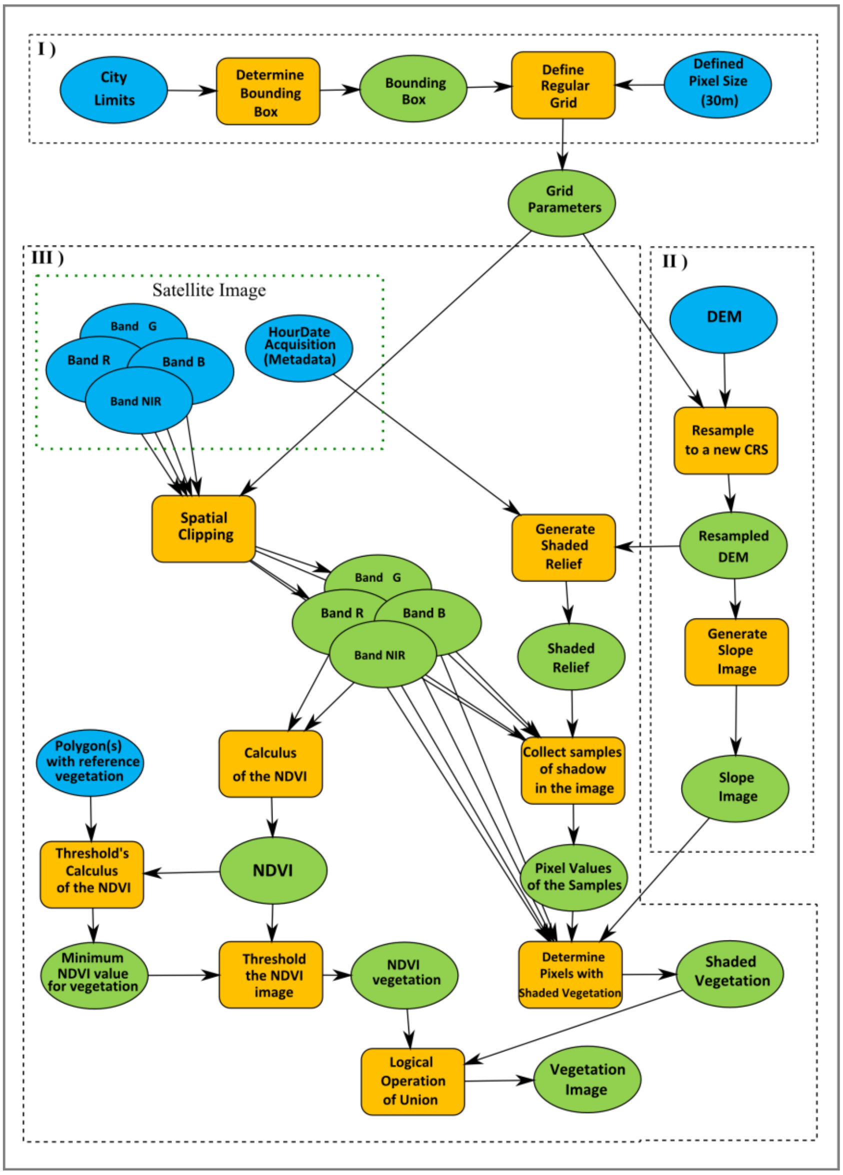
PROCESSING WORKFLOW

The processing of all data was performed using the software Matlab 2012 and the maps were produced with ArcGIS 10.2.2. Nevertheless, this works detail each step through processing workflows in order to be implemented in any other Geographic Information System (GIS) software.

Figure 5 shows the general model for generation of a binary image that represents vegetation areas from the materials (inputs). It has the geoprocessing sequence (workflow) to achieve a final product. In this model, blue ellipses are the data input. The yellow rectangles refer to geoprocessing. Green ellipses are the geoprocessing's results (or outputs). The lines connecting the elements are known as connectors and indicate the workflows.

The work is divided into three groups: I, II and III. The groups I and II have the need to be executed only once. The work of the group III will be performed for each satellite image.

Figure 5 – Processing Workflow for Generation of Vegetation Image



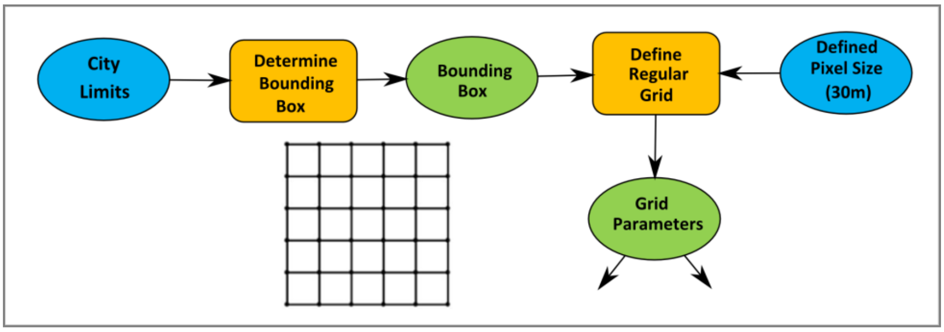
Source: Own authorship (2015).

The group I works are designed to determine the parameters of the regular grid that mean the coordinates of the starting pixel, pixel size and number of rows and columns of the image.

The coordinates of the city boundaries describe the contour of the area to be mapped. With these coordinates you can determine the bounding box for selecting a spatial area of satellite images and DEM. By setting the spatial resolution of the product is calculated the number of rows and number of columns (Figure 6).

R. bras. Geom., Curitiba, v. 5, n. 3, p. 343-360, jul/set. 2017.

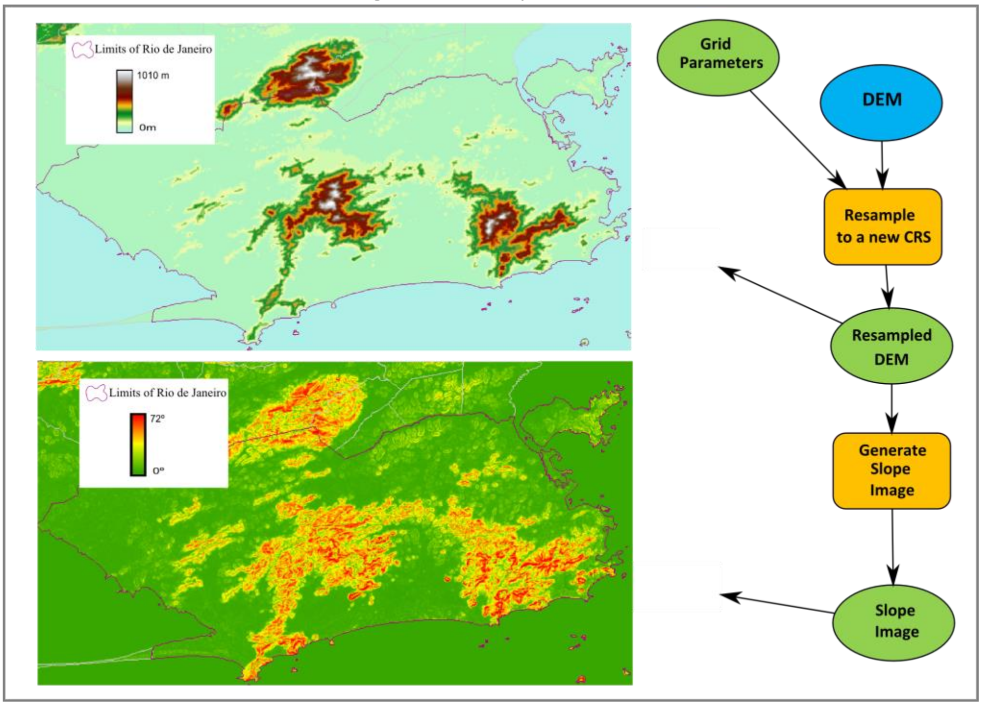
Figure 6 – Determination of the regular grid parameters



Source: Own authorship (2015).

The group II works provide inputs to the process of group III, being the outputs: the resampled DEM and the slope image. The performed operations correspond to the resampling of the DEM to the defined CRS and the generation of the slope image using the resampled DEM (Figure 7).

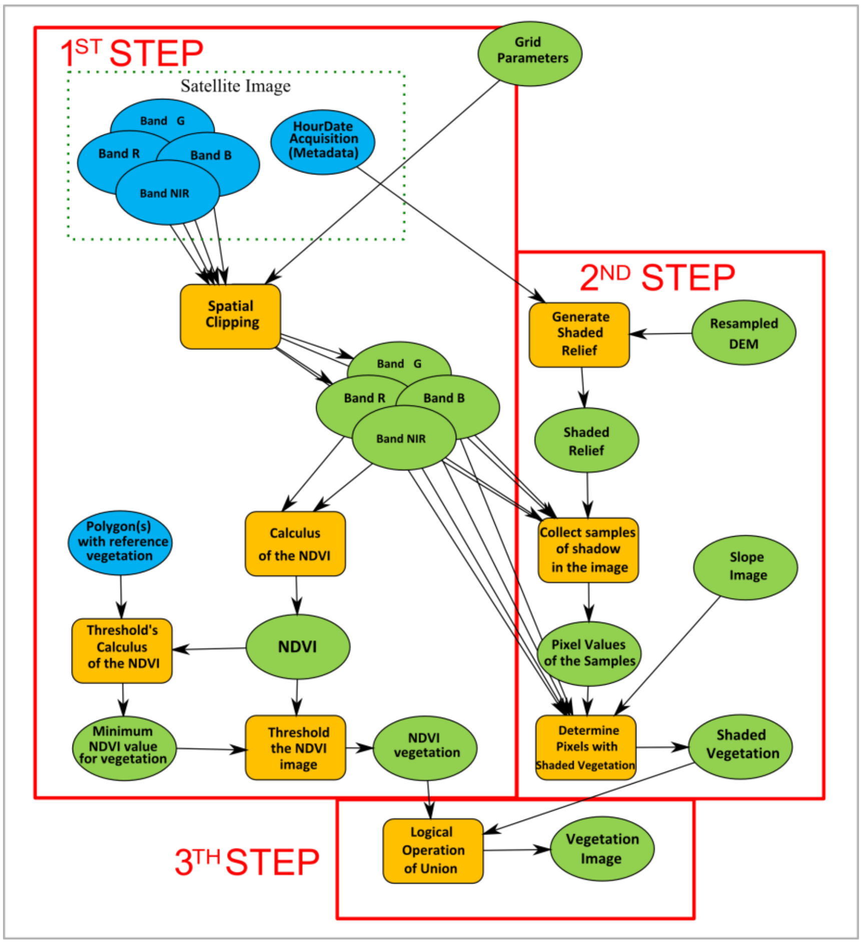
Figure 7 – Group II works



Source: Own authorship (2015).

The group III works aim to generate the vegetation's binary image whose the value 1 (true) signifies the presence of vegetation and the value 0 (false) means the absence. These works can be divided into three steps (Figure 8). The first step seeks to create the binary image of the NDVI vegetation and the second step, the binary image of the shaded vegetation. The last step corresponds to a logical operation of union between the results of the two previous steps.

Figure 8 – Steps of Group III



Source: Own authorship (2015).

The first step begins by the spatial clipping of the image bands in accordance with the grid parameters. Then, the R and NIR bands were used to calculate the NDVI image. With the support of the polygon(s) created by the operator, it is possible to collect samples of the pixel values of vegetation in the adopted region as reference and thus determine the lower threshold value of NDVI. With this minimum NDVI value for a reference area of vegetation is performed thresholding the NDVI image, that is, to create a binary image wherein for values above the lower threshold pixel becomes true (existence of vegetation) or false (no vegetation).

In the second step, the shaded relief image is created from the resampled DEM and knowing the date and time of the image acquisition. In the shaded relief image, the shadow regions are characterized by pixel values very close to zero, these pixels will serve as a reference in order to collect samples of shadows in the bands of satellite images.

From the shadow samples in Landsat image, it was possible to determine all the shaded pixels in the same picture, using the method of the parallelepiped (based on the Gaussian distribution of the sample).

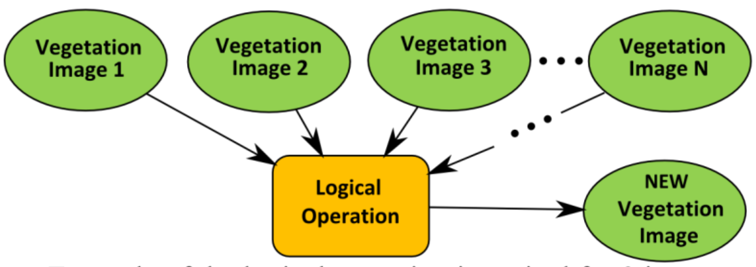
In this same process, the shadow image is filtered by the slope image, as many shadow pixels can fall into water regions due to the fact that shade and water having very similar spectral responses, however the slope in vegetation regions with shadow usually quite high, unlike the regions with water, where the slope is almost nil, equating to level surfaces. The output of this process is a binary image for the shadow areas.

With the resulting binary images from the two previous steps, it proceeds to the third step, that is, the logical operation of union among them, compounding the vegetation image which is associated with that satellite image. This binary image, the product of all geoprocessing, denotes the presence or absence of vegetation in each pixel.

VEGETATION IMAGE OBTAINED FOR THE SAME YEAR

The group III works will be repeated for three or more images of the same year, being calculated a new image of vegetation from the resulting vegetation images of the third step (Figure 9). The adopted criterion to determine whether a pixel of the new image is or not vegetation was that, for each pixel, over 50% of all images of the year correspond to vegetation. This procedure eliminates the effects caused by noise and reduces the uncertainties that are attributed to the thresholding process.

Figure 9 – New resultant binary image



Exemple of the logical operation in a pixel for 3 images

Image 1	T	F	T	T	F	F	F	T
Image 2	T	F	T	F	T	F	T	F
Image 3	T	F	F	T	T	T	F	F
Percentage	100	0	67	67	67	33	33	33
NEW	**T**	**F**	**T**	**T**	**T**	**F**	**F**	**F**

Source: Own authorship (2015).

This new resulting image is now considered definitely the image that represents the vegetable coverage areas for a given year.

If there are satellite images with nulls (no information), these pixels will not participate in the percentage score for the generation of new image of vegetation.

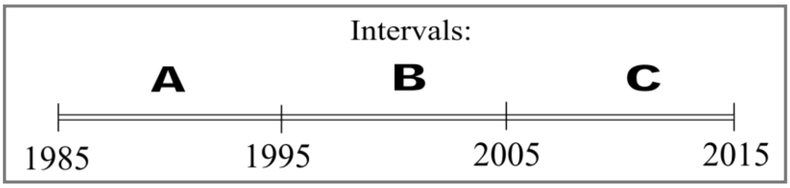
Besides the reducing of errors caused by noises and clouds on the image classification, considering the case where is used only one image at a certain time of year, this percentage value enables us to state that a region was (or not) mostly covered by vegetation during that year, adding the fact that the position of the sun (and shade) varies each season.

COMPARISON OF VEGETATION IMAGES THROUGHOUT THE YEARS

The spatio-temporal change of vegetation canopy to be represented is determined from vegetation images for each analysed year. With them it is possible to determine the occurrence of changes on each time interval.

Considering the four resulting vegetation images for each year, the 30-year period is divided into three intervals (Figure 10).

Figure 10 – Time Intervals



Source: Own authorship (2015).

There are 16 possible situations of an area to be covered or not by vegetation. These situations are defined in each pixel in the following classes:

1: Unchanged vegetation (with vegetation cover over the whole period). Sequence: T-T-T-T.

2: Area without the occurrence of vegetation throughout the period. Sequence: F-F-F-F.

3: Deforested in the period C (2005-2015). Sequence: T-T-T-F.

4: Deforested in the period B (1995-2005). Sequence: T-T-F-F.

5: Deforested in the period A (1985-1995). Sequence: T-F-F-F.

6: Reforested in the period C. Sequence: F-F-F-T.

7: Reforested in the period B. Sequence: F-F-T-T.

8: Reforested in the period A. Sequence: F-T-T-T.

9: Reforested in B and deforested in C. Sequence: F-F-T-F.

10: Reforested in A and deforested in B. Sequence: F-T-F-F.

11: Reforested in A and deforested in C. Sequence: F-T-T-F.

12: Deforested in B and reforested in C. Sequence: T-T-F-T.

13: Deforested in A and reforested in B. Sequence: T-F-T-T.

14: Deforested in A and reforested in C. Sequence: T-F-F-T.

15: Reforested in A, deforested in B and reforested again in C. Sequence: F-T-F-T.

16: Deforested in A, reforested in B and deforested again in C. Sequence: T-F-T-F.

The vegetation change image corresponds to the result of the classification of the pixels in accordance with the defined classes above, where each pixel is assigned the value 1 to 16.

The classes 1 (unchanged vegetation) and 2 (area without the occurrence of vegetation) are areas that were not modified throughout the analyzed period.

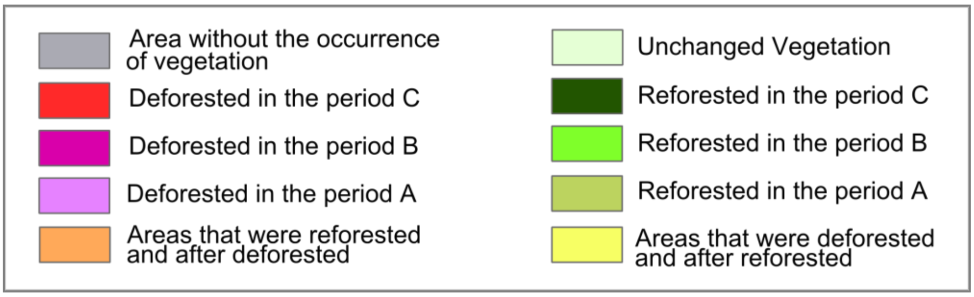
The classes from 3 to 8 represent the areas that happened only one change over the 30 years, on the other hand the classes from 9 to 16 had more than one change.

Classes 3, 4 and 5 represent the evolution of deforestation for each interval. Similarly, the classes 6, 7 and 8 represent the evolution of reforestation.

In this paper, it was refereed to generalize the classes from 9 to 16 in two new classes. The first generalization represents the areas that was reforested in a certain period and deforested in another and the second generalization corresponds to the areas that was deforested in a certain period and after reforested.

Thus, the classes' generalization is illustrated in the legend (Figure 11). The red tint highlights the deforestation, on the other hand, the green tint makes reference to reforestation. Unchanged regions are symbolized with neutral colors.

Figure 11 – Legend for the vegetation change image's classes



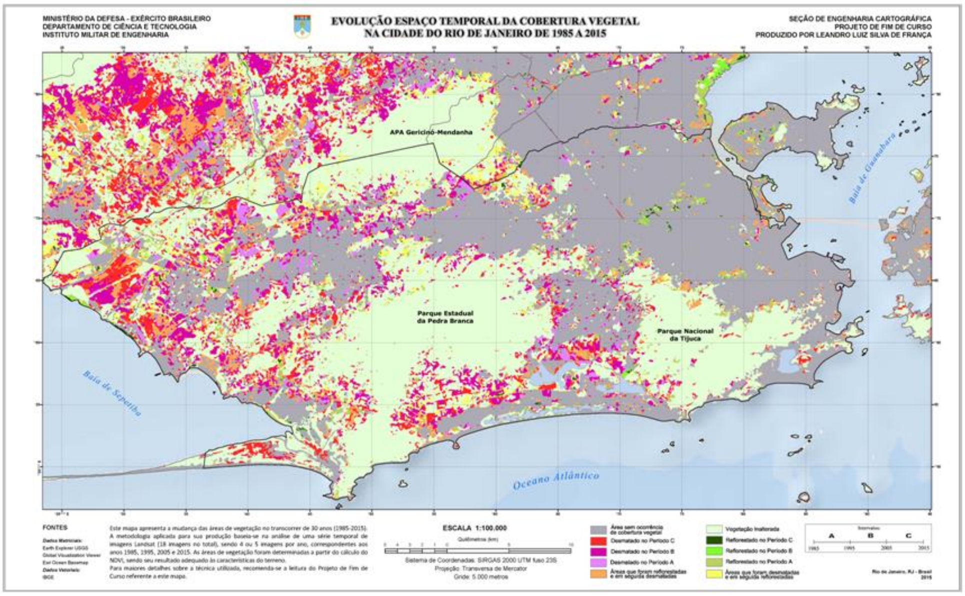
Source: Own authorship (2015).

RESULTS

The result corresponds to a thematic map that approaches the vegetation areas in the city of Rio de Janeiro during the period of 1985 to 2015, being represented on the scale 1:100,000 in the dimensions of 77 cm x 47 cm (FRANÇA, 2015).

It provides information about the changes related to deforestation and reforestation. This map (Figure 12) also displays the dynamics of changes in vegetation and can distinguish the speed and acceleration of its evolution.

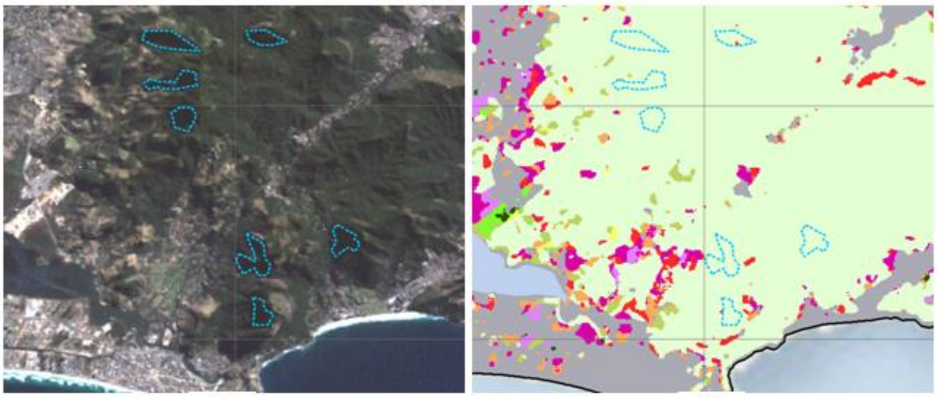
Figure 12 – Map of spatial-temporal change of the vegetation in the city of Rio de Janeiro



Source: Own authorship (2015).

Figure 13 shows the effectiveness of the methodology for identification of vegetation in shaded areas. The areas with blue-hatched contours correspond to vegetation with shadow (Figure 13a). They were correctly classified as vegetation (Figure 13b).

Figure 13 – (a) vegetation areas with shadow; (b) correctly classified areas



(a) (b)

Source: Own authorship (2015).

The Table 2 presents the results for classification of shaded vegetation for pixel samples collected within polygons by visual inspection.

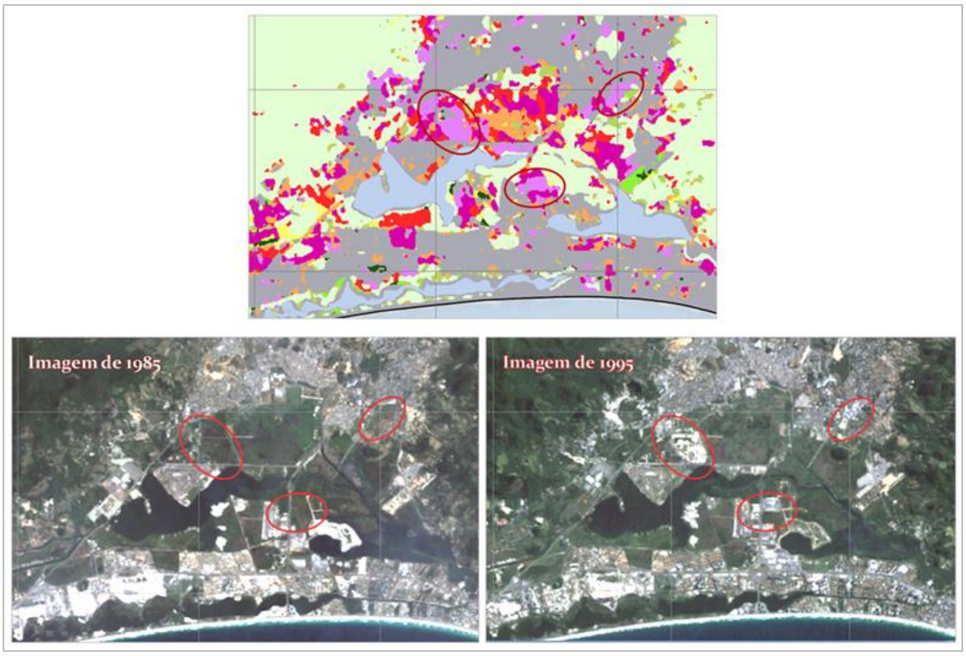
Table 2: Results for the correct classification of shaded vegetation.

Sample	Number of Pixels	Correctly Classified	Percentage of Hits
Shaded Vegetation	2143	2079	97,01%

Source: Own authorship (2015).

Figure 14 illustrates the vegetation class which was deforested in the period 1985-1995 for a given area of the city. They are highlighted within the ellipses.

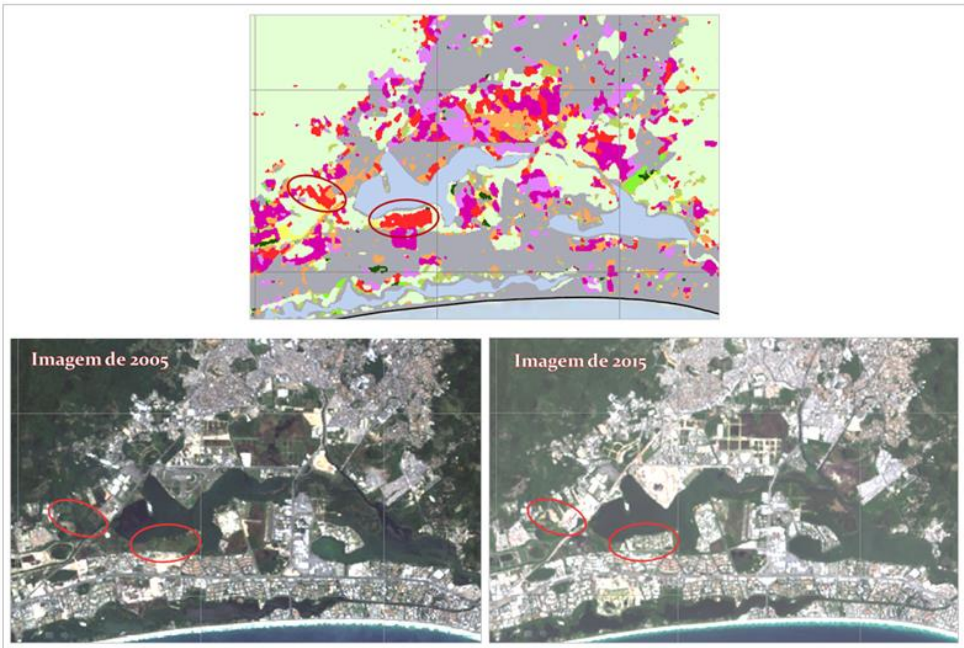
Figure 14 – Vegetation deforested in the period A (1985-1995)



Source: Own authorship (2015).

Similarly, figure 15 illustrates the class which was deforested in the period 2005-2015. These areas are highlighted in ellipses.

Figure 15 – Vegetation deforested in the period C (2005-2015)



Source: Own authorship (2015).

The Table 3 proves the efficiency of thedeforestation's classificationwithin each time interval. The pixel samples also were collected with polygons by visual inspection.

Table 3: Results for the correct classification of the deforestation

Sample	Number of Pixels	Correctly Classified	Percentage of Hits
Deforested in A	1089	981	90,08%
Deforested in B	1232	1143	92,78%
Deforested in C	1221	1199	98,20%

Source: Own authorship (2015).

It is noted that the results is even better in the period C due to the Landsat 8 images which has high radiometric resolution.

CONCLUSION

The objective of this study was to represent, from a set of satellite images, as the vegetation of a particular area has changed during the passage of time in a synoptic way, in other words, through a map.

The developed methodology allowed more consistent results with the vegetation reality. This occurred due to the combination of the NDVI with the relief features by mean of the DEM. Furthermore, the use of multiple images (with different sun positions for each analyzed year) corroborated statistically for more accurate results.

In general, this methodology can be used to represent the extent of environmental impacts in certain places. It allows the monitoring and comparison between different times.

In terms of evaluation of a large city, the evolution of deforestation is highly related to urban expansion toward the green areas. Therefore, this work is enough useful to measure the urban growth over the course of time. This is a possible study as a product of this work, but your goal is more comprehensive, because it aims to serve as a source for various environmental analysis.

Mapeamento da Evolução Espaço-Temporal da Cobertura Vegetal em Áreas de Relevo Acidentado

RESUMO

O propósito deste artigo é apresentar uma forma de mapear as mudanças ocorridas em regiões de cobertura vegetal utilizando-se de imagens multiespectrais, sendo aplicada uma metodologia especialmente adequada às regiões de relevo acidentado, onde, eventualmente, acidentes orográficos atuam como obstáculo para propagação da radiação solar e, consequentemente, propiciam a ocorrência de regiões com sombra. A detecção de vegetação nessas regiões não é eficaz usando apenas técnicas como o *Normalized Difference Vegetation Index* (NDVI). Para validar a técnica de mapeamento proposta, foi elaborado um mapa que apresenta a evolução da cobertura vegetal no município do Rio de Janeiro cujo relevo apresenta uma diversidade de morros e montanhas que caracterizam um relevo acidentado. As técnicas utilizadas para determinação da vegetação que superarão as limitações provocadas pelas sombras são baseadas nos resultados obtidos do NDVI e na simulação das regiões sombreadas a partir do Modelo Digital de Elevação (MDE) para o momento de aquisição da imagem pelo satélite, permitindo a identificação de áreas de vegetação em regiões com pouca iluminação. Estas técnicas foram aplicadas a uma série com intervalo de dez anos para imagens de satélite Landsat considerando o período de 1985 a 2015. A combinação do NDVI com o MDE e imagens com distintas direções de insolação permitiu obter resultados mais coerentes com a realidade da cobertura vegetal, chegando-se a mais de 97% de acerto. O produto final deste trabalho corresponde a um mapa que identifica a mudança na vegetação durante esses 30 anos.

PALAVRAS-CHAVE: Cobertura Vegetal. Sensoriamento Remoto. Detecção de Vegetação Sombreada. NDVI.

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